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GREAT LAKES ICE SEASON OF 1968

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ABSTRACT

Theory and present practice of ice forecasting are discussed. Ice coverage charts for each 10th day of the 1967-1968 season are presented. The freezeup of the Straits of Mackinac and an unusual ice formation on southern Lake Michigan are described in some detail.

1. INTRODUCTION

This study is a direct continuation of work reported by Snider (1967). Recent efforts have aimed at the development of improved techniques for ice forecasting and improved methods of presentation for both current and prognostic ice information. Ice distribution charts exactly analogous to those of the previous article, but containing certain additional information, are presented. By comparing the two series of charts, one can now begin to form an idea of which ice features are relatively the same from year to year, and which vary with changing meteorological conditions.

Details of the method used to construct ice distribution charts can be found in the previous article. Basically, a series of ice synoptic charts is assembled. This includes all available aerial reconnaissance charts and all useful satellite photographs, arranged in chronological order, together with charts of plotted surface reports at intervals varying from 1 to 5 days depending on the rapidity of changes. Each plotted chart is analyzed as completely as data will permit. Complete analyses are then prepared for each 10th day, extrapolating and interpolating as necessary, largely on the basis of concurrent synoptic weather charts.

During the winter of 1967-1968 there was a large increase in the amount of ice data reported by the U.S. Coast Guard. Both shore stations and cutters underway made detailed daily observations of ice conditions throughout the winter. Other data were of about the same quantity and quality as in the previous year.

Economic conditions brought about a great demand for the services of the Great Lakes shipping fleet this year. Although the gross tonnage carried in 1967 was down slightly from the record-breaking amount of 1966, the carrying capacity of the fleet was also reduced. This achievement would not have been possible had not the lakes been kept open unusually late in 1967. The effort expended to open navigation early in 1968 suggests another banner year is in prospect. Ice reports issued by the Weather Bureau were written in great detail and were widely studied with great interest. The Coast Guard used the full resources of its men and equipment to keep channels open to the greatest possible extent.

2. THEORY OF ICE FORECASTING

Formation, thickening, movement, changes in internal structure and external morphology, interaction with water, air, and land, and eventual melting of lake ice are the result of an infinite variety of physical processes. Many of these processes and the resultant ice features have been described by Marshall (1966). Ice forecasting techniques in the Soviet Union utilize data on temperature, area, depth, and currents of the water; current and prognostic air temperature, humidity, and winds; solar radiation and cloud cover data; the effects of ground water influx and precipitation; and heat transfer through the bottom (Shulyakovskii, 1966).

Formation of ice on the surface of a lake requires removal of heat to lower water temperature to the freezing point, then further removal which is taken from latent heat. This heat removal is accomplished primarily through conductive exchange with the overlying air. Small contributions are made by radiation, evaporation, and loss of sensible or latent heat to frozen precipitation. It is opposed as heat is added by upwelling warm water, warm precipitation, and solar or atmospheric radiation.

Upwelling is especially important during the freezeup season when the deep water is relatively warm and storms maintain stirring. Net radiation during freezeup is very small, as minimal solar radiation added to radiation from heavy clouds is nearly counterbalanced by outward radiation from the water. During breakup, cloud cover is much reduced and insolation is much greater. Richards (1963) has noted that it takes far fewer thawing degree-days to destroy ice than freezing degree-days to produce it. Much of the difference, no doubt, is due to insolation.

At the present state of the art, the most useful ice forecasts can be produced on the hypotheses that 1) rate of ice formation is proportional to the accumulation of freezing degree-days; 2) ice on deep water is destroyed, partially or wholly, by storms (this effect gradually diminishes as the winter season advances); 3) ice is destroyed rapidly in the spring by a combination of thawing degree-days and insolation; and 4) ice is dragged along with the wind, subject to the constraints of shoreline configuration, its own rigidity, and Coriolis force—it is often melted when moved onto deeper water.

TABLE 1.—*Forecast opening date*

Port	Icebreaker	Natural	Actual opening date
Duluth	Apr. 7	Apr. 15	Apr. 3
Sault Ste. Marie	Mar. 31	Apr. 17	Apr. 2
Straits of Mackinac	Mar. 30	Apr. 13	Mar. 30
Escanaba	Apr. 14	Apr. 15	Mar. 31
Green Bay	Apr. 4	Apr. 15	Apr. 7
Alpena	Mar. 16	Apr. 5	Mar. 24
Cleveland	Mar. 20	Mar. 29	Mar. 26
Buffalo	Apr. 10	Apr. 20	Apr. 18

3. ICE FORECASTING TECHNIQUES

The forecast technique described by Oak (1955) remains in use. Oak and his associates developed a series of regression equations relating February mean temperatures to opening dates of various Great Lakes ports. A single forecast, issued around the 1st of March, was sufficient. Modifications to that method have been made from time to time, and a major extension is now described.

It was noted early that, while Oak's technique gave generally good results, there were occasional spectacular failures. Investigation showed these failures to be associated with abnormal economic conditions. A booming economy might entice shippers to accept unusual risks in forcing through ice; a lethargic economy might allow an ice-free port to wait days or even weeks before it is visited, or "open." In order to improve their predictions of opening dates, forecasters began acquiring economic data, primarily by asking shipping companies about their plans. Significant improvements to forecasts were made in some, though not all, cases. It was simply not possible for a meteorologist to assemble all the needed economic data, nor for him to properly analyze the data he had. In short, the forecasts suffered from a severe lack of scientific purity.

The year 1968 saw the introduction of a new technique. Two forecasts were presented rather than one. A "natural opening date" was defined as the date upon which "natural melting will clear the ice to the extent that it is no longer of significance to unescorted unreinforced vessels." An "icebreaker opening date" was defined as the date after which "an average effort by Coast Guard cutters will maintain a channel into the port."

The forecast dates were computed from regression equations exactly like those used by Oak; but the new equations were based on longer series of data, and the data were stratified prior to derivation, using a method developed by Linklater (1963). Linklater classified the economy of each year from 1907 through 1962 as "booming, firm, recession, or depression." Classification was based on economic reports of the Lake Carriers Association. One set of regression equations, relating February mean temperatures to opening dates in "booming economy" years was used to forecast icebreaker opening dates. It was assumed that in these years, shipping companies and their supporting services made every effort to get the season underway at the earliest profitable date. A second set of equations based on similar data for "firm economy" years was used to forecast natural opening dates. These equations were found to be very similar to those used by Oak. Data for recession and depression years were discarded. It was assumed that presence or absence of ice was not related to port opening dates in those years.

Dates determined from the regression equations were then modified slightly by subjective consideration of 1) existing ice cover at forecast time and 2) long-range temperature forecasts for March. Results are listed in table 1. The ports of Detroit and Toledo were already being kept open by icebreakers when the forecast was issued. Actual opening dates suggest that 1968 was a year of "high" if not "booming" economic activity. Two ports, Duluth and Escanaba, opened before their forecast icebreaker opening dates. Duluth opened 1 day after the Soo Locks, Escanaba 1 day after the Straits of Mackinac. This probably indicates that, with modern technology, local ice in such ports is no longer a determining factor—it is the distant bottleneck that must be watched. Most channels were actually opened by icebreakers. However, icebreakers were not always available at every point where effective action was possible. As long as allocation of limited icebreaking facilities must remain an administrative decision, verification figures should not be scrutinized too closely.

A single forecast, issued around the 1st of March, will no longer suffice for all the varied activities affected by Great Lakes ice. There is a need for current ice information and outlooks throughout the winter. Any forecast issued must be updated and expanded as later data become available. Techniques for developing such advisory information are still quite subjective. They lean heavily on the Weather Bureau's long-range forecast program. Freezing degree-day data are computed from both past and prognostic temperatures from November through March. Thawing degree-day data are similarly computed during March and April. The weakest link in present ice forecasting techniques is the inability to predict storm winds more than 48 hr in advance. This

TABLE 2.—*Experimental ice forecasts derived from graphs*

Date prepared	First significant ice	Ice-covered	Ice-free
Traverse Bay area			
Nov. 30	Dec. 26	Feb. 13	
Dec. 18	Dec. 30	Feb. 21	
Jan. 2		Feb. 16	
Jan. 16		Feb. 12	
Feb. 1		Feb. 15	Apr. 10
Verification	Dec. 31	Feb. 17	Apr. 14
Western Lake Erie			
Nov. 30	Dec. 26	Jan. 23	
Dec. 18	Dec. 28	Jan. 18	
Jan. 2			
Jan. 16			
Feb. 1			Apr. 4
Verification	Dec. 28	Jan. 9	Apr. 1

weakness, in itself, demonstrates the need for constant updating of forecasts.

Tentative relationships have been worked out between the accumulation of freezing degree-days and amount of ice cover on various portions of the Great Lakes. Several such relationships were taken from the work of Richards (1963) and of Noble and Ewing (1967). It was noted that there is a rough correlation between the number of freezing degree-days required to produce a given ice cover and the depth of the water. This correlation was applied to each major basin of the lakes not discussed in existing literature. Relationships thus derived were modified slightly by comparing freezing degree-day computations for the winter of 1966–67 with ice distribution charts for that season prepared by Snider (1967).

For each of 23 areas of the Great Lakes, a tentative value of freezing degree-day accumulation for the first significant ice and the first ice cover, and a value of thawing degree-day accumulation for ice-free conditions, have been determined. Forecast dates were obtained by applying these critical values to graphs of prognostic degree-day accumulations. The graphs were constructed for Fort William, Escanaba, Sault Ste. Marie, Detroit, and Toronto. They were based on 1) observed temperatures up to the forecast date, 2) prognostic temperatures for the next 30 days, and 3) normal temperatures for the rest of the winter.

Experimental forecasts derived from these graphs were prepared twice monthly from Nov. 30, 1967, through Feb. 1, 1968. Results are encouraging, but much more work is needed before an established procedure can be described. Two examples of forecasts prepared by this method are given in table 2. Verification for the two areas listed was better than average—some of the forecasts were very poor. Still, considering that forecast parameters were based on little more than educated guesses, it is not disappointing. Once regression equations have been developed, this system should give more useful results than that now used for published forecasts. It is totally independent of economic or operational factors, it is applicable to both freezeup and breakup seasons, and it incorporates the best available prognostic data.

Two preliminary ice advisories were issued during February, giving brief summaries of existing ice cover and early indications for the opening of navigation, as determined from both the methods mentioned above. A preliminary ice report on February 26 gave details of existing ice conditions. Regular ice reports were issued each Monday from March 4 through April 15, in much the same format as that described by Oak (1955). Intermediate advisories, each Wednesday and Friday, discussed the effect of current and expected storms and prognostic temperatures on the ice.

4. THE 1968 SEASON

The 1968 ice season was notable for a steady growth of bay and shore ice through the winter and an erratic ebb and flow of deep-water ice owing to frequent winter storms. Lake Erie at times was 100 percent ice covered, and Lake Superior for a few days was 90 percent covered. Winter gales, however, especially over Lake Superior, so dislodged the deep-water ice that there was little continuity in the formation patterns from week to week. On the other hand, the bay ice closely adhered to the normal pattern of development and deterioration.

The breakdown in the thermocline, opening the door to significant deep-water ice formation, on January 1 or 2 was followed by comparatively protracted periods of abnormally low temperatures. Thus, the development of deep-water ice, once started, was fast and extensive in spite of the winter gales.

Freezing degree-days began to accumulate rapidly over the Upper Lakes during the last week of November, and over the Lower Lakes by mid-December. Bay ice closed the harbors in the northern lakes to small craft early in December, but the southern lake ports remained relatively ice free through much of the winter. Ice did form in the Lower Lake ports during December and January, but the normal activities of the fish tugs, car ferries, and colliers kept the channels and docks open into February.

The first (fig. 5) of the series (figs. 1–32) of ice cover charts shows conditions for December 31. Shore and bay ice over the northern lakes has developed rapidly in below-zero temperatures. Some ice has begun to appear in the southern lakes where temperatures had also turned much colder. Cold, calm weather prevailed through January 10, encouraging dramatic ice growth over all the Great Lakes. Shore ice has built out into the open water, and some solid cover extends completely across a portion of Lake Erie.

Northeasterly storms and above-normal temperatures during mid-January broke up most of the deep-water ice, but some drift and floe ice persisted. Shore and bay ice continued to develop through the end of January, while deep-water ice formation was retarded by northwesterly gales. Comparatively warm temperatures and gales through early February discouraged ice growth except in the northern lakes where temperatures remained below freezing (figs. 10–13).

Moderate winds and lower temperatures during the middle of February restored the ice pattern to normal midwinter conditions, especially on Lake Erie, which had about 80-percent solid ice cover. As the cold trend continued through the remainder of the month, considerable deep-water ice spread over all the lakes with the exception of Lake Ontario (figs. 17, 20).

March began on a cold note but with strong northerly gales early in the month causing some drifting of the deep-water ice into the southern portion of each of the lakes. Temperatures began to moderate during the middle of March marking the end of significant ice formation and the beginning of the spring thaw. The thickness of bay ice on the northern lakes ranged from 10 to 30 in. and from 5 to 15 in. on the southern lakes (figs. 23, 26, 28).

The termination of the 1968 season was essentially a mirror image of the beginning of the season. Prolonged unseasonably warm temperatures early in March, punctuated by heavy rains and disruptive winds, harried the vast ice surfaces into early dissolution (figs. 30, 32). So ended the Great Lakes 1968 ice season, notable for the abrupt and seemingly whimsical reversals of the controlling weather elements.

5. FREEZING OF THE STRAITS

The 1967 freezeup of the Straits of Mackinac exemplified the ice season as a whole throughout the Great Lakes. During the early weeks of the season, ice did form in the Straits area; but owing to winter storms it did not consolidate, and the Straits remained open through the initial two-thirds of December.

Demand for Great Lakes shipping services during late 1967 was high. The navigation season extended right up to the end of the year. During the final week, rapidly developing ice required intense efforts by Coast Guard cutters to keep channels open and to escort vessels through threatening areas. Ice reports filed by personnel on board these cutters permit us to study this year's freezeup in unusual detail.

A prolonged cold spell set in during the latter half of December, with temperatures falling well below the zero mark. Between Christmas and New Year's Day, ice developed with dramatic suddenness (figs. 2–4). Ice continued to thicken through early January, although some small areas were temporarily opened by shifting winds (figs. 6–9). By January 10 the Straits were icebound, though there was one final forced transit on January 16.

Higher temperatures during the latter half of January temporarily stalled the growth of the ice, until much colder weather prevailed again during February. By the end of February the ice was solid from the Mackinac

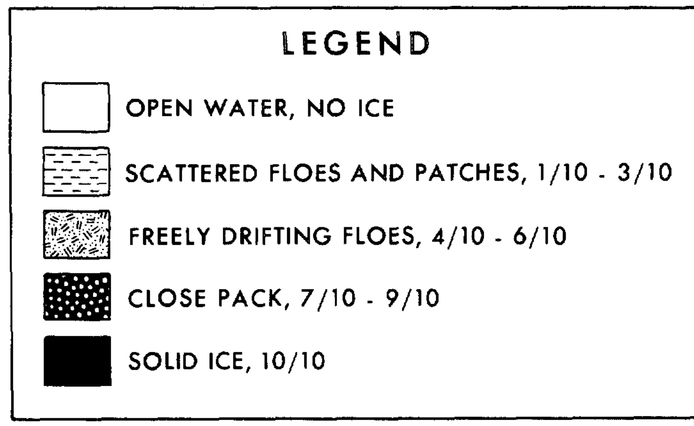

FIGURE 1.—Key to ice concentration shown by figures 2 through 33.

Bridge eastward beyond Bois Blanc Island into the northern tip of Lake Huron. Westward, the solid ice covered most of northern Lake Michigan and had thickened to 10 to 30 in. The ice surface was relatively smooth except along its eastern and western boundaries where heavy windrows had developed.

An ice bridge, which is normally an important winter transportation link between Bois Blanc and Beaver Islands, remained intact throughout the winter. Many ice bridges linking the mainland and the northern chain of islands forming Georgian Bay remained serviceable through most of the winter.

6. ICE ON SOUTHERN LAKE MICHIGAN

An unusual ice formation occupied portions of southern Lake Michigan during the late winter and spring of 1968. At various times it lay in areas of navigational or recreational importance and was cause for concern by persons with interests in several different fields. Ice of such magnitude is uncommon on this deep-water, relatively low-latitude basin. It was not a particularly cold winter around southern Lake Michigan, and the reason for such ice formation is not immediately apparent. Detailed examination is in order.

Prior to February 12, the offshore waters of southern Lake Michigan remained nearly ice free. Ice had been present intermittently in some harbors, and an ice fringe had formed along the east shore. On that date, thin ice cover suddenly appeared on the lake off Chicago. This ice cover was shown by satellite photograph to extend north-northeastward in a band about 25 mi wide and 100 mi long (fig. 14).

The freezing degree-day accumulation at Milwaukee had, by February 12, reached 684. It would be easy to attach too much significance to this number. It may be somewhere near a limiting value. However, the distribution of ice shows that something more than air temperature was involved in its formation and survival.

Temperatures then prevailing in the area would have permitted ice formation at the rate of about 1 in. per day. Warm upwelling brought about by normal wind-driven water turbulence can usually melt several inches of ice per day. One can conclude only that, for one reason or another, vertical motion within this portion of the water

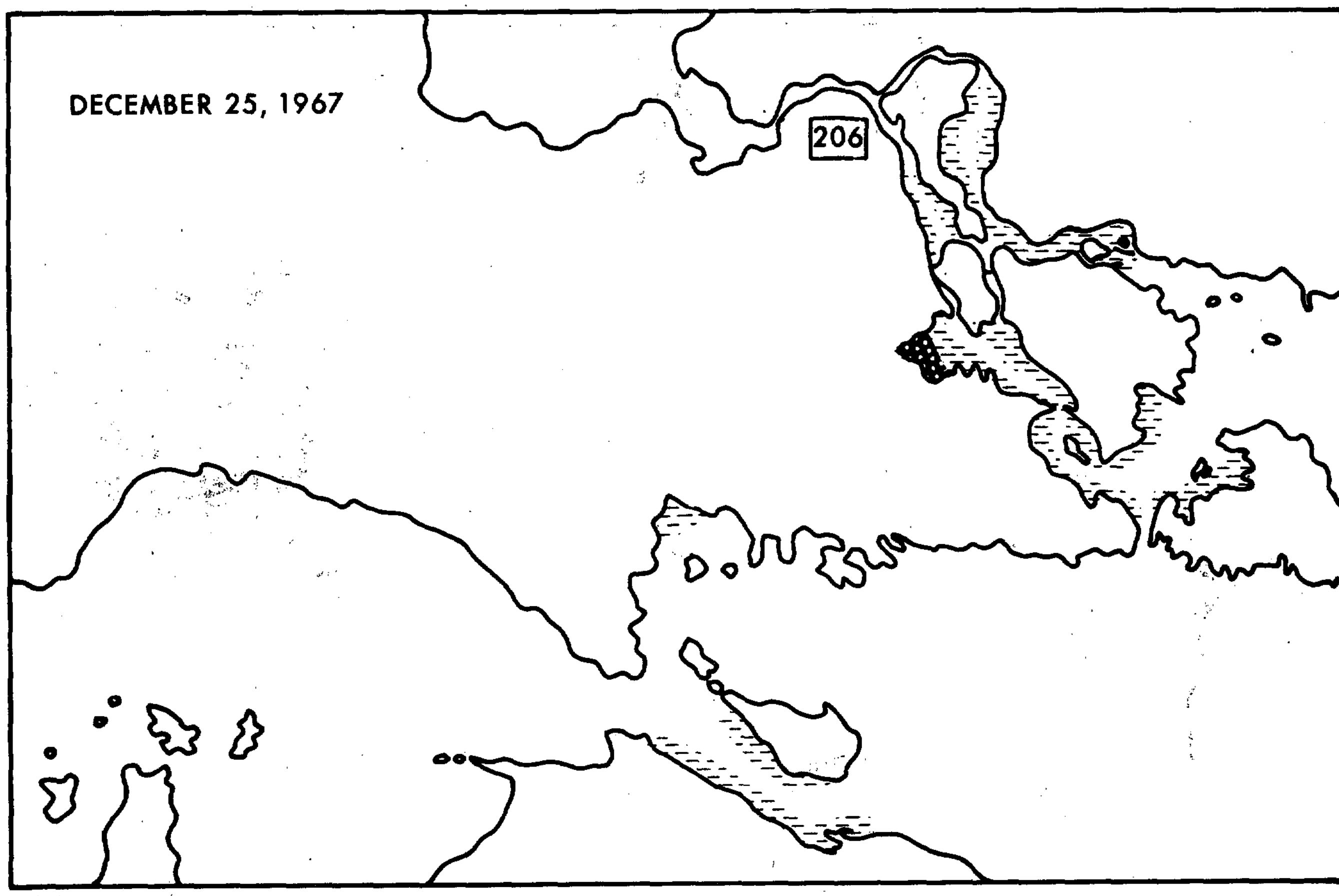

FIGURE 2.—Ice on the Straits of Mackinac, Dec. 25, 1967. The boxed number is the accumulation of freezing degree-days at Sault Ste. Marie.

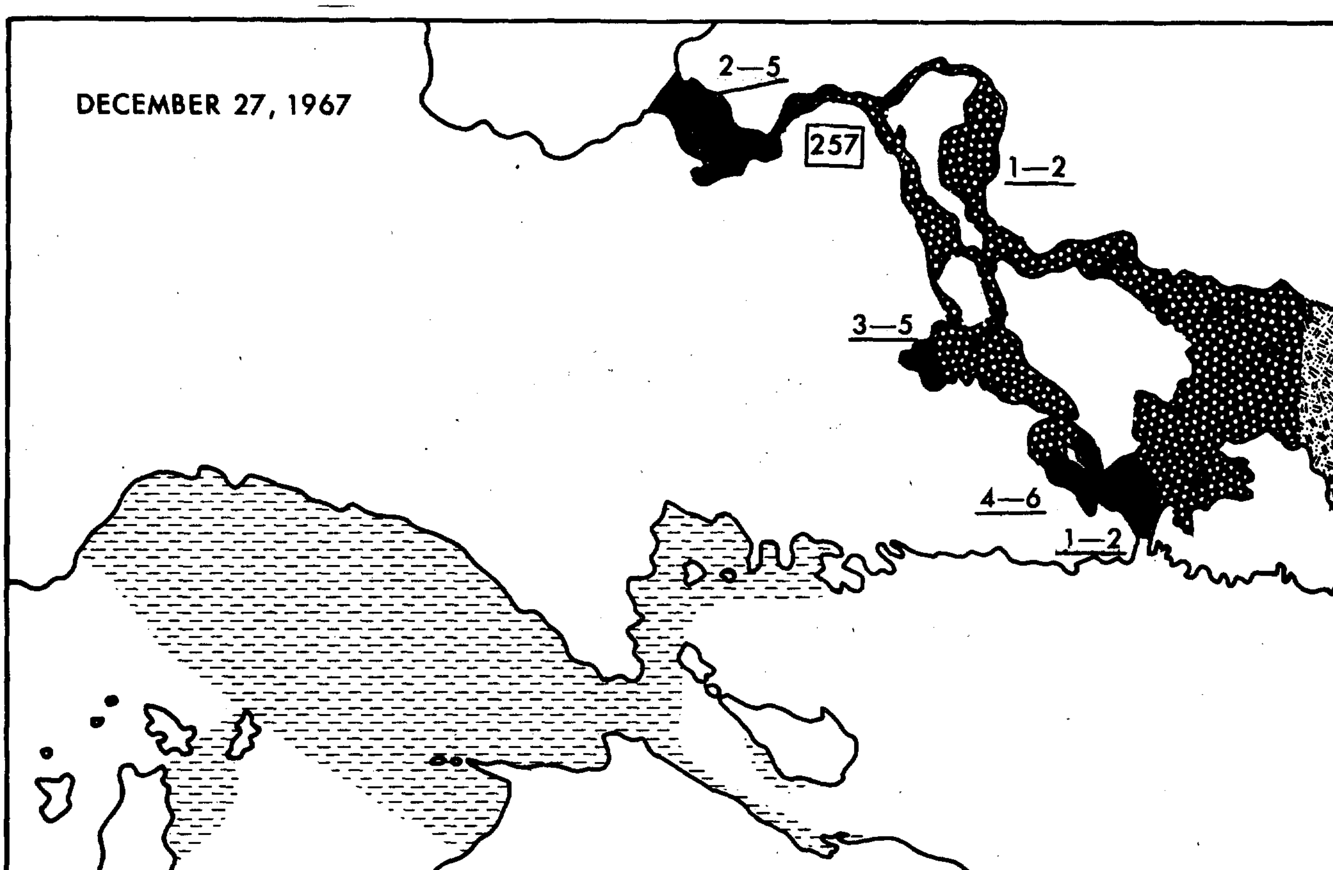

FIGURE 3.—Ice on the Straits of Mackinac, Dec. 27, 1967. The boxed number is the accumulation of freezing degree-days at Sault Ste. Marie. Other numbers are reported ice thickness in inches.

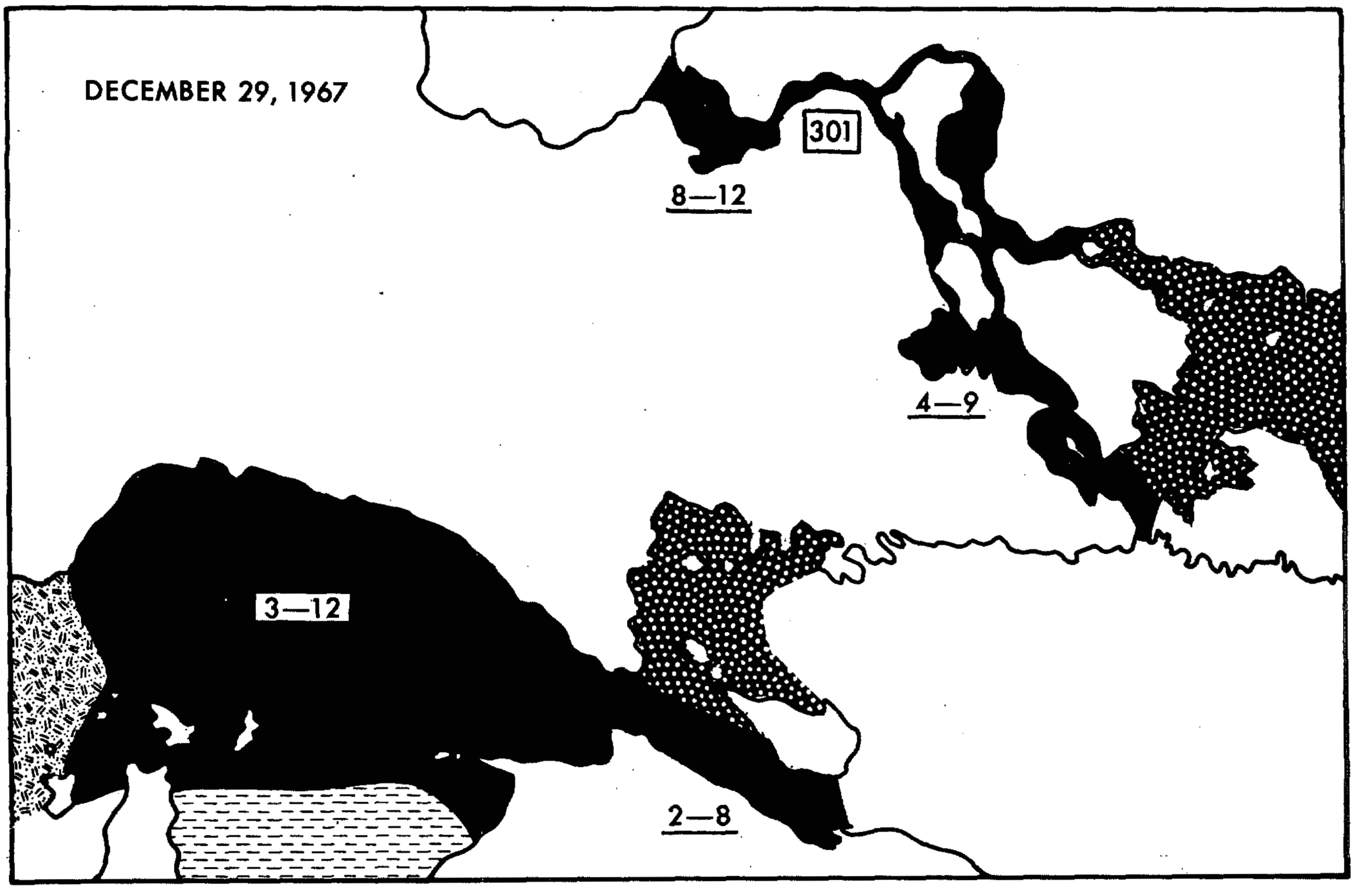

FIGURE 4.—Ice on the Straits of Mackinac, Dec. 29, 1967 (see fig. 3).

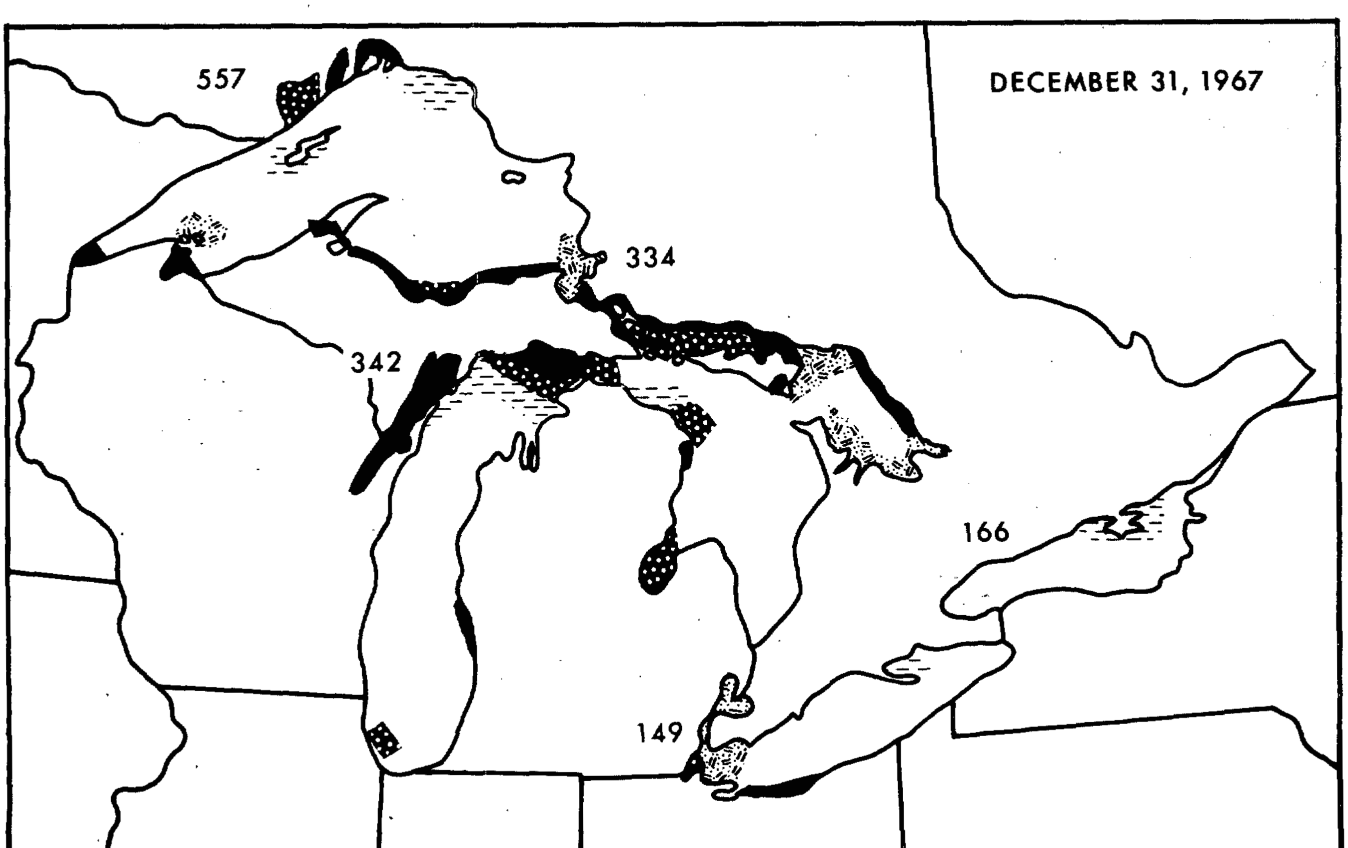

FIGURE 5.—Ice concentration, Dec. 31, 1967 (see fig. 1 for key relating shading to concentration). Numbers are accumulations of freezing degree-days.

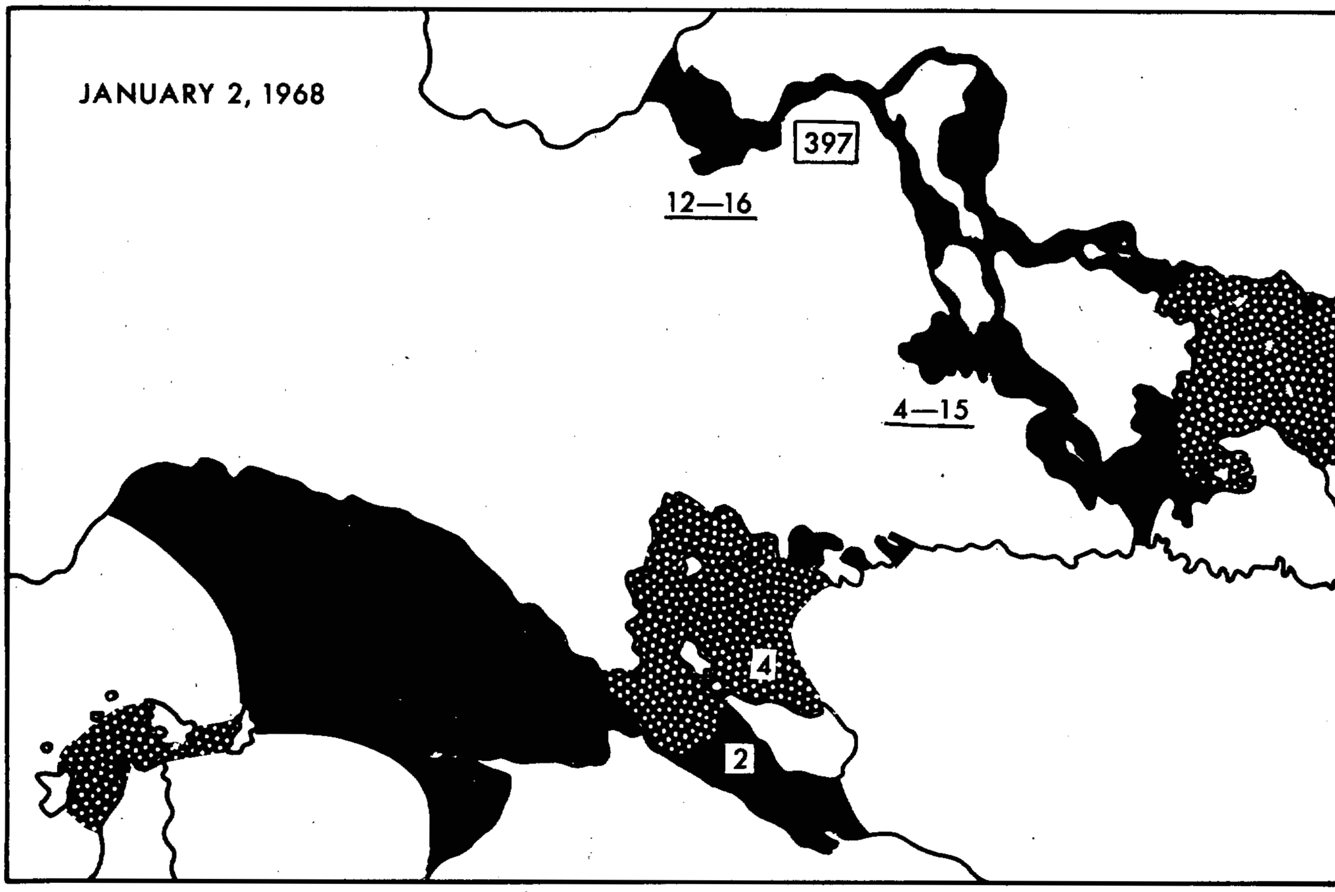

FIGURE 6.—Ice on the Straits of Mackinac, Jan. 2, 1968 (see fig. 3).

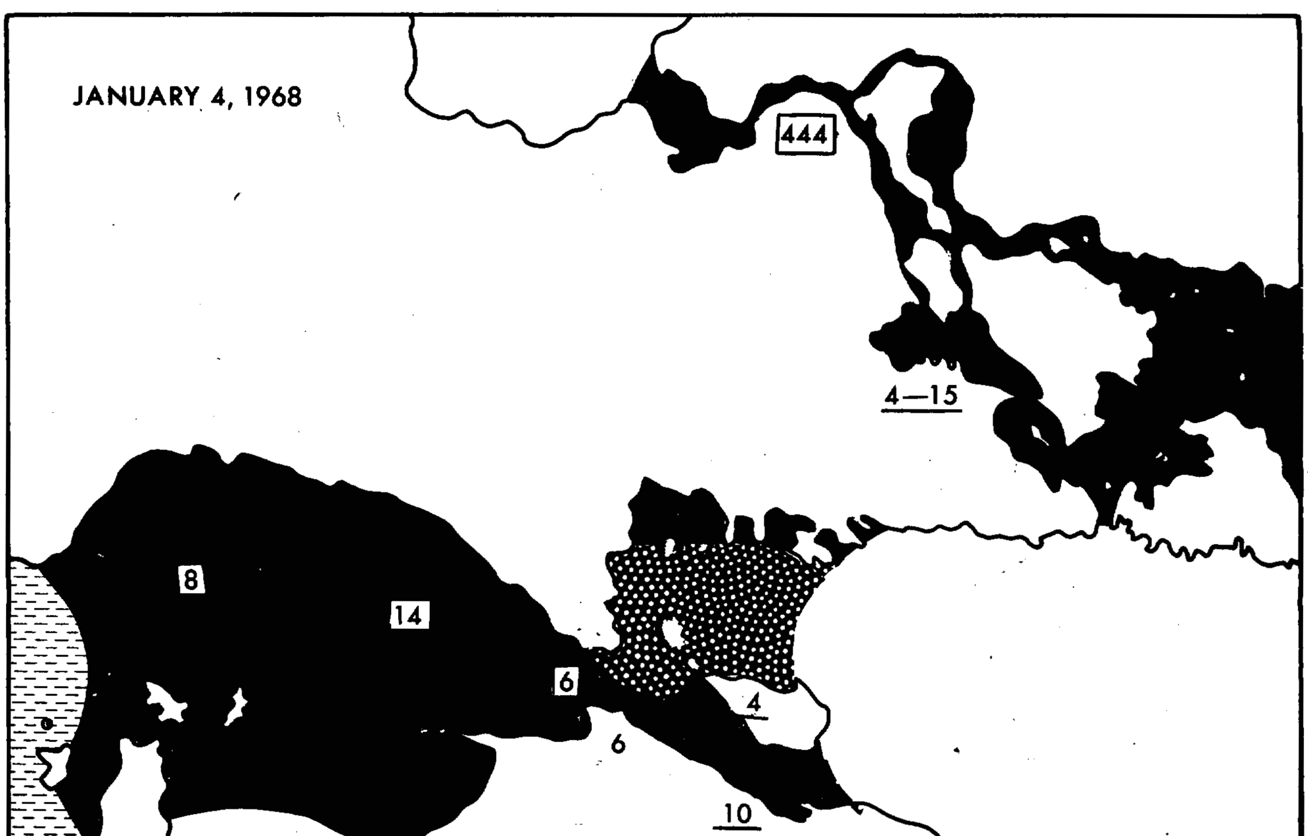

FIGURE 7.—Ice on the Straits of Mackinac, Jan. 4, 1968 (see fig. 3).

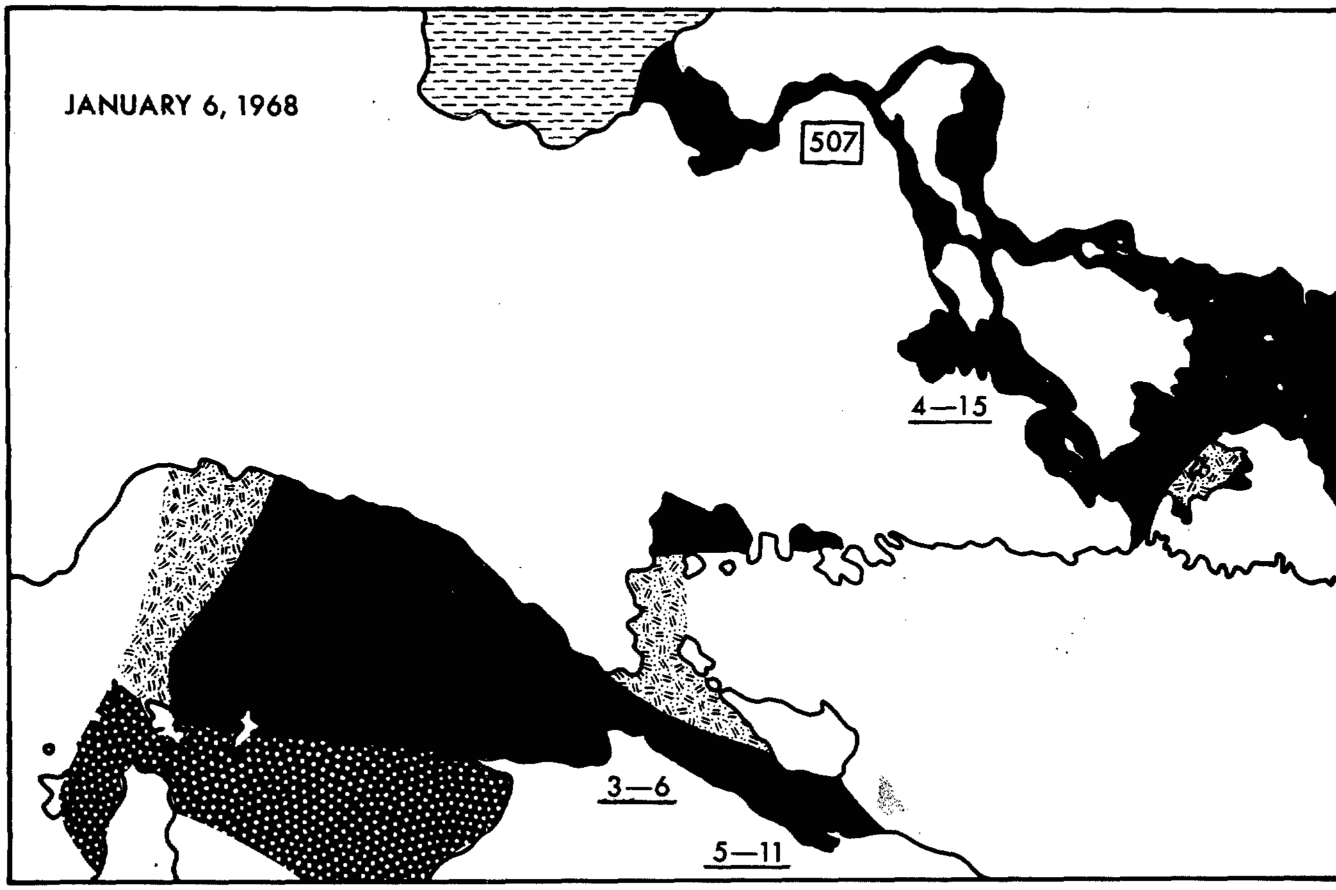

FIGURE 8.—Ice on the Straits of Mackinac, Jan. 6, 1968 (see fig. 3).

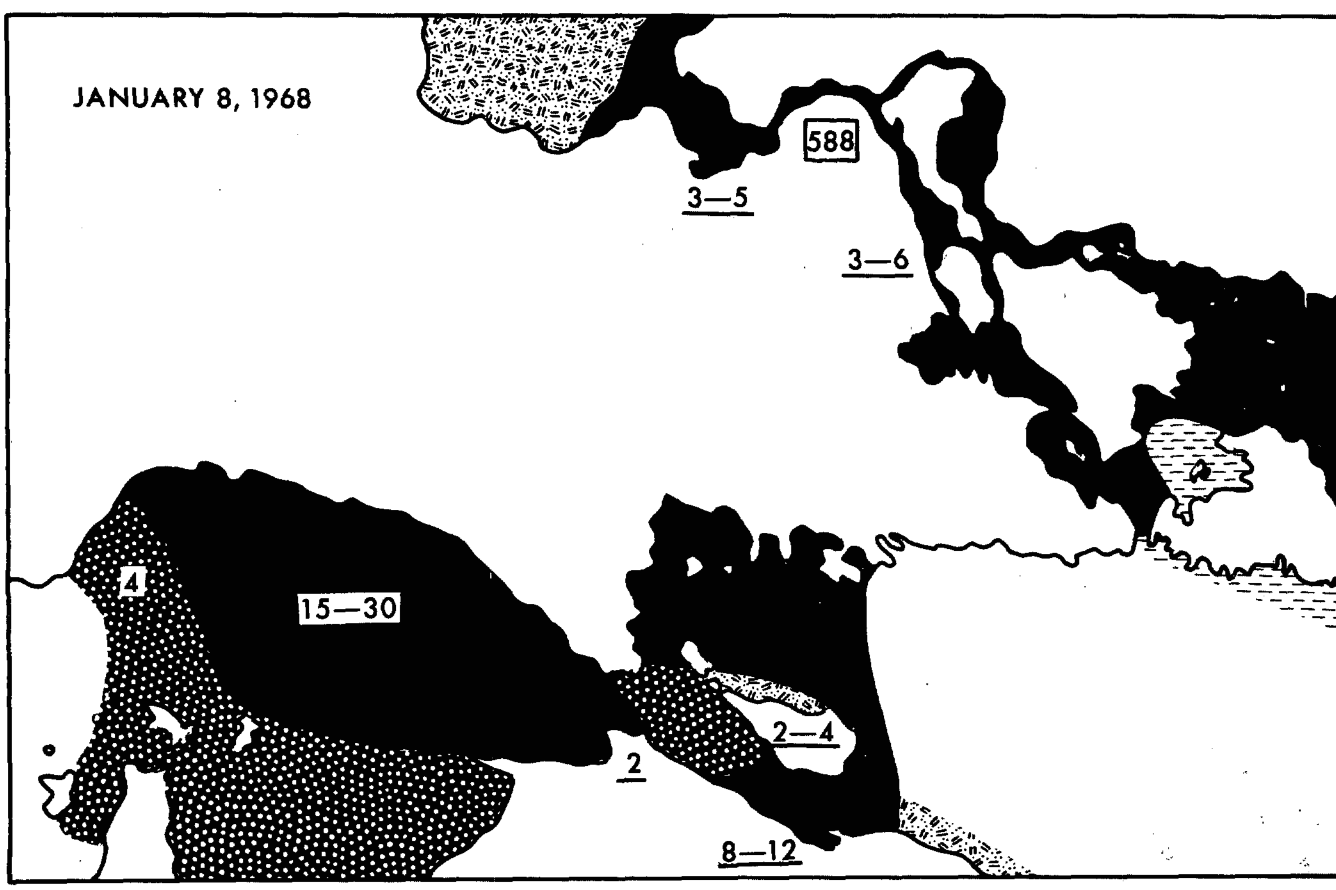

FIGURE 9.—Ice on the Straits of Mackinac, Jan. 8, 1968 (see fig. 3).

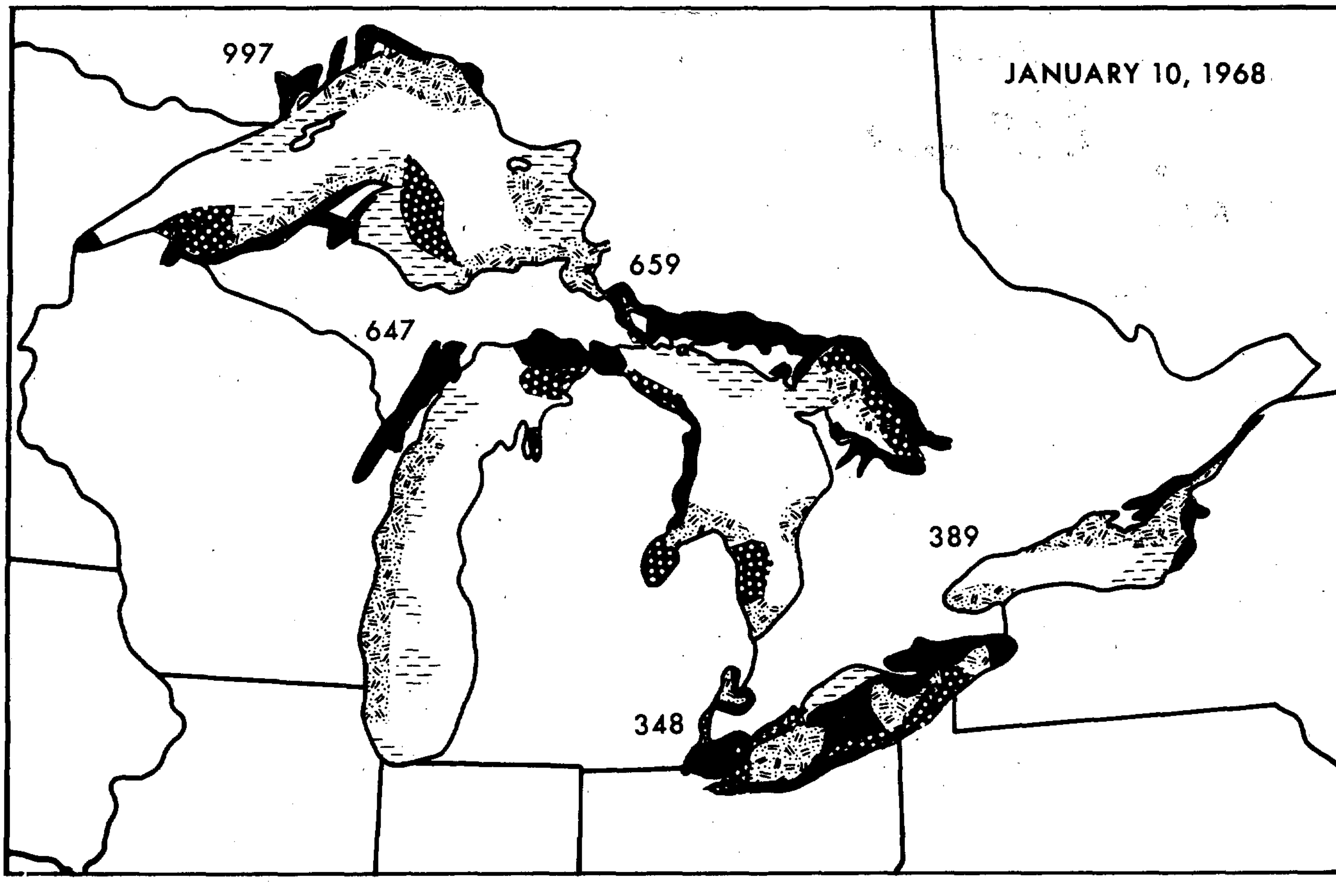

FIGURE 10.—Ice concentration, Jan. 10, 1968 (see fig. 1).

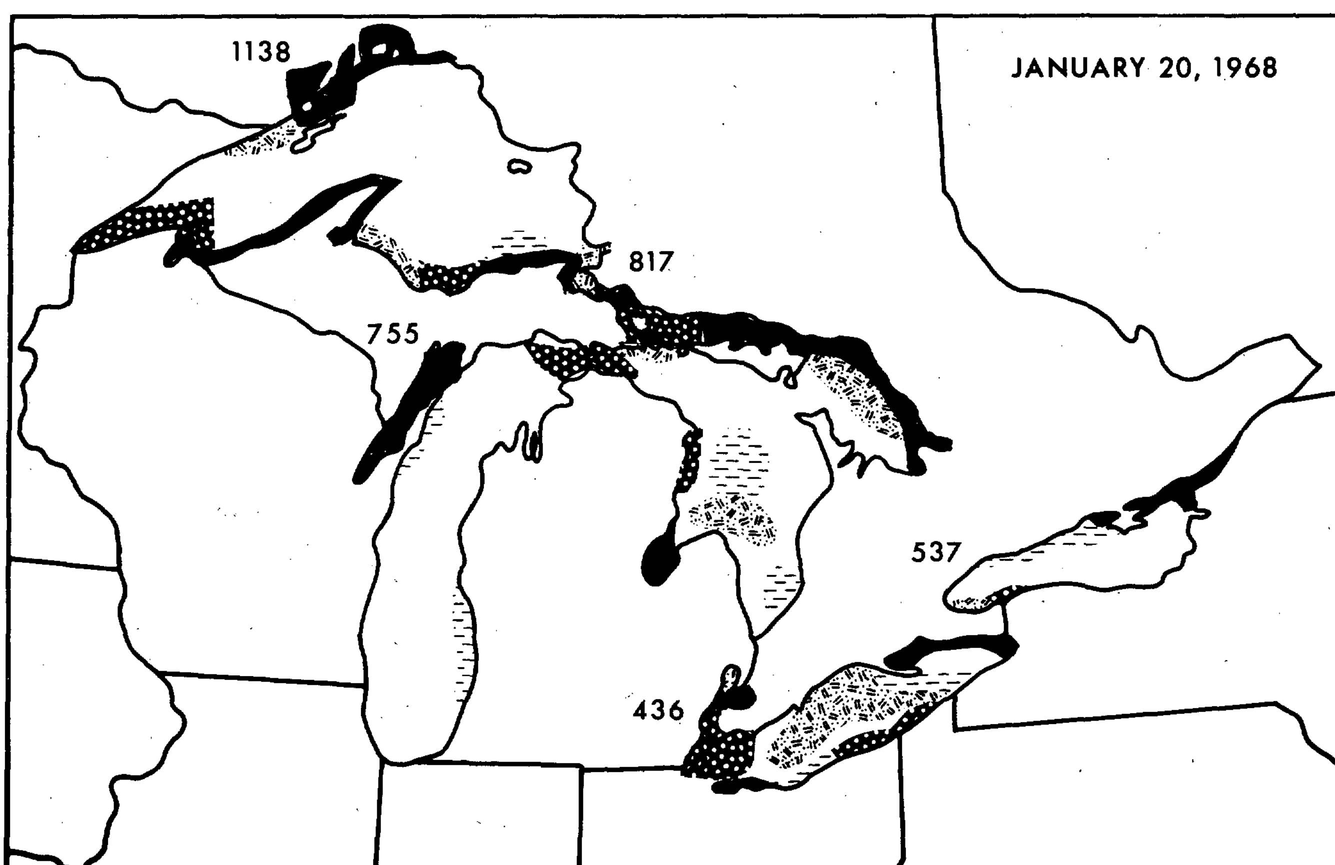

FIGURE 11.—Ice concentration, Jan. 20, 1968 (see fig. 1).

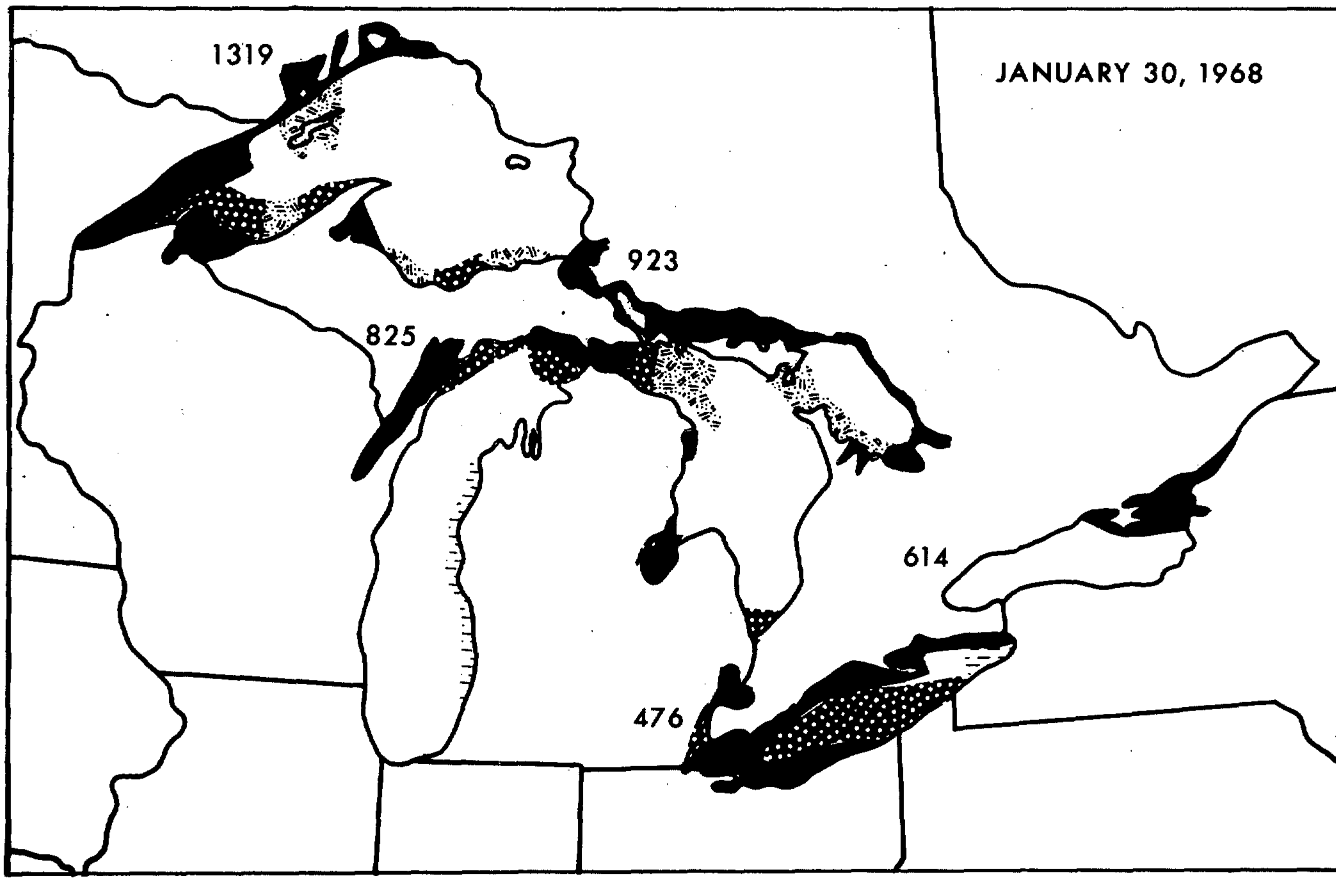

FIGURE 12.—Ice concentration, Jan. 30, 1968 (see fig. 1).

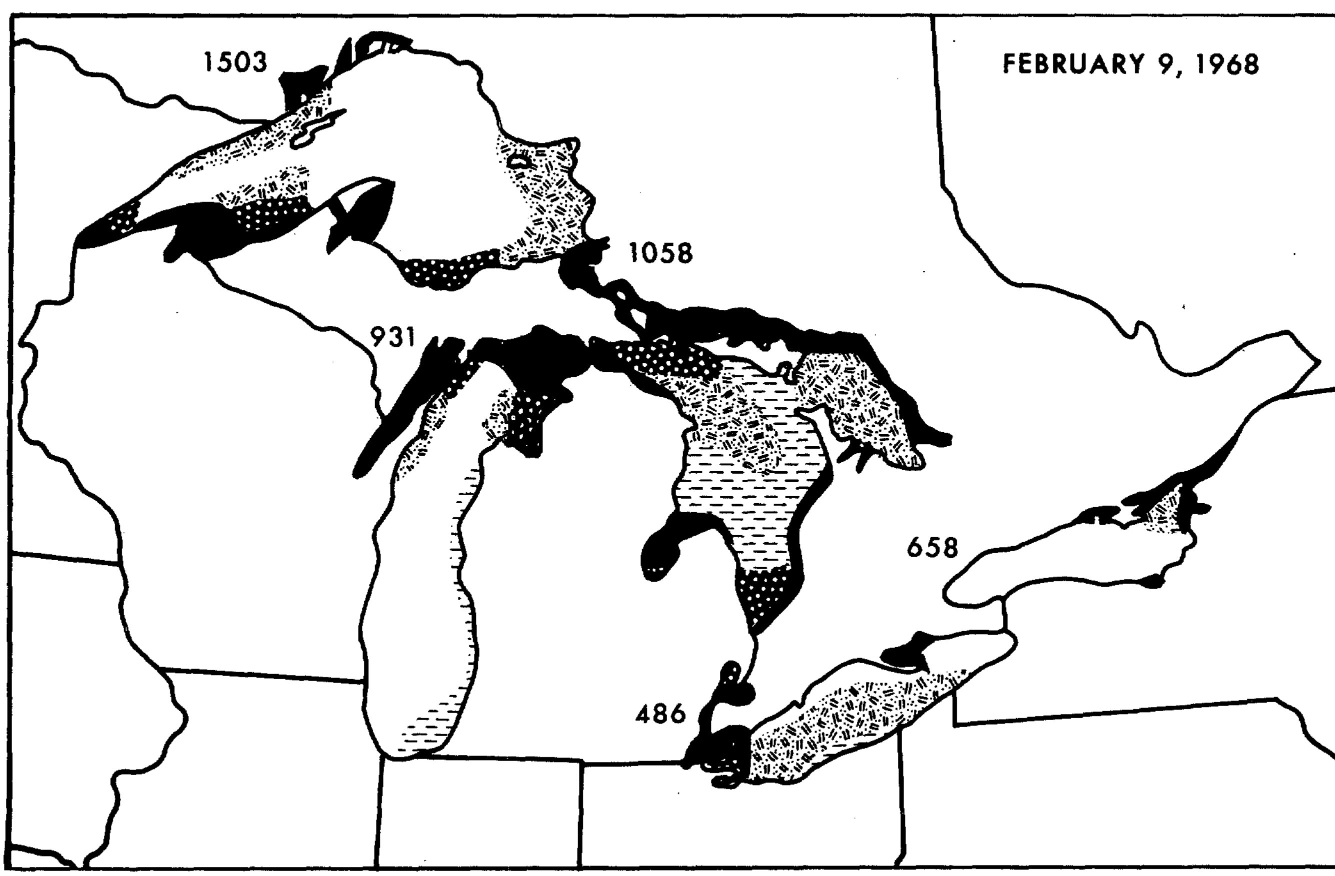

FIGURE 13.—Ice concentration, Feb. 9, 1968 (see fig. 1).

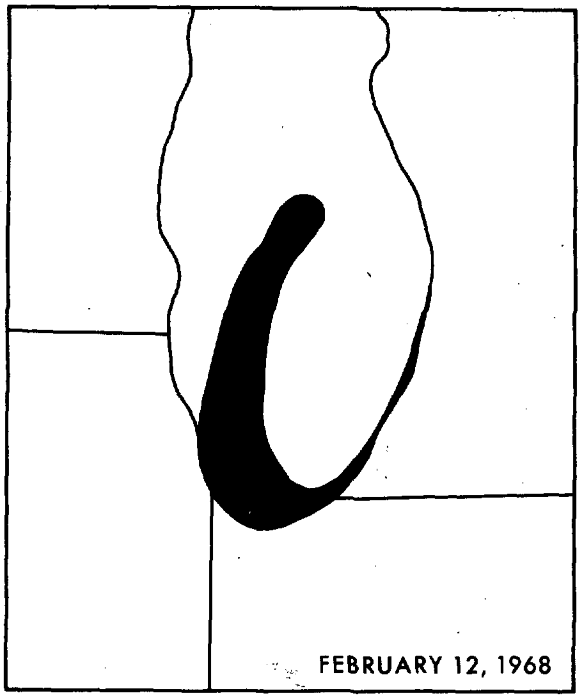

FIGURE 14.—Ice on southern Lake Michigan, Feb. 12, 1968 (see fig. 1).

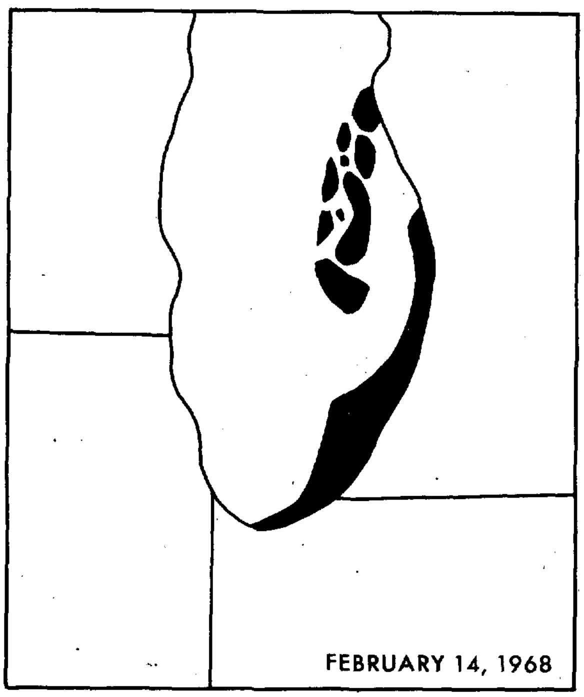

FIGURE 15.—Ice on southern Lake Michigan, Feb. 14, 1968 (see fig. 1).

mass temporarily ceased. The reason may lie in an unusual time-space distribution of winds, unusual subsurface conditions, or a combination of both.

Immediately after it formed, the ice mass began drifting eastward at 1 to 2 kt— estimated to be about 10 percent of the surface wind. Indications are that it thickened while crossing the central portion of the lake, reaching a thickness of perhaps 3 in. Irregular melting then began as it encountered more normal water conditions not far from the east shore.

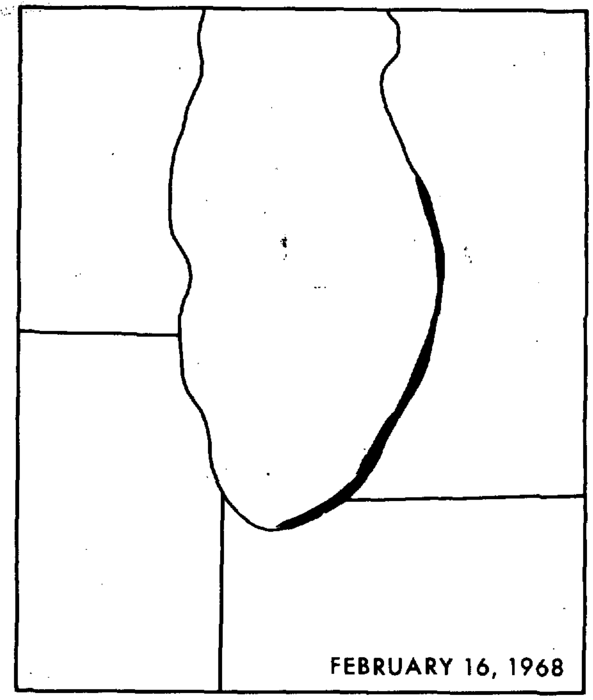

FIGURE 16.—Ice on southern Lake Michigan, Feb. 16, 1968 (see fig. 1).

On February 14, ice floes began piling up on the beach from Michigan City to Grand Haven (fig. 15). Windrows averaging 40 in., extending in places to the bottom, were reported 1 mi off Holland. Drifting ice floes were still found in the open lake on the 15th, but on February 16 all the remaining ice piled along the shore in a strip 1 to 3 mi wide with windrows up to 60 in. (fig. 16).

There is no direct evidence that more ice bands formed in the open lake, but such may have been the case. The east shore ice jam widened and spread northward even as winds continued to compact it against the beach and to pile up windrows. One fortuitous observation suggests that many minor ice bands may have formed. A narrow north-south strip of ice was reported 18 mi off Milwaukee on March 4. With easterly winds, it moved onto the west shore the following day.

Cross-lake car ferries first reported difficulty with ice on February 20. Coast Guard cutters attacked the formations between February 21 and 28, attempting to maintain channels into principal ports. Their observations provide a wealth of detail on size, shape, and movement of this unusual ice feature. On February 24, north-northeast winds detached the north end and moved it 5 to 8 mi offshore. West winds on the 27th and 28th jammed it back in place. Windrows up to 150 in. were reported off St. Joseph on the 24th. Diminishing wind pressure thereafter allowed gravity to break down windrows somewhat and spread ice cover westward (figs. 18, 19, 21).

On March 6 and 7, northeast winds again detached the northern part of the ice band and moved it out into the lake (fig. 22). The southern portion remained intact until March 9, when south winds blew the Michigan City-St. Joseph portion offshore. The broad shore lead was closed again on the 11th by north winds. On March 16,

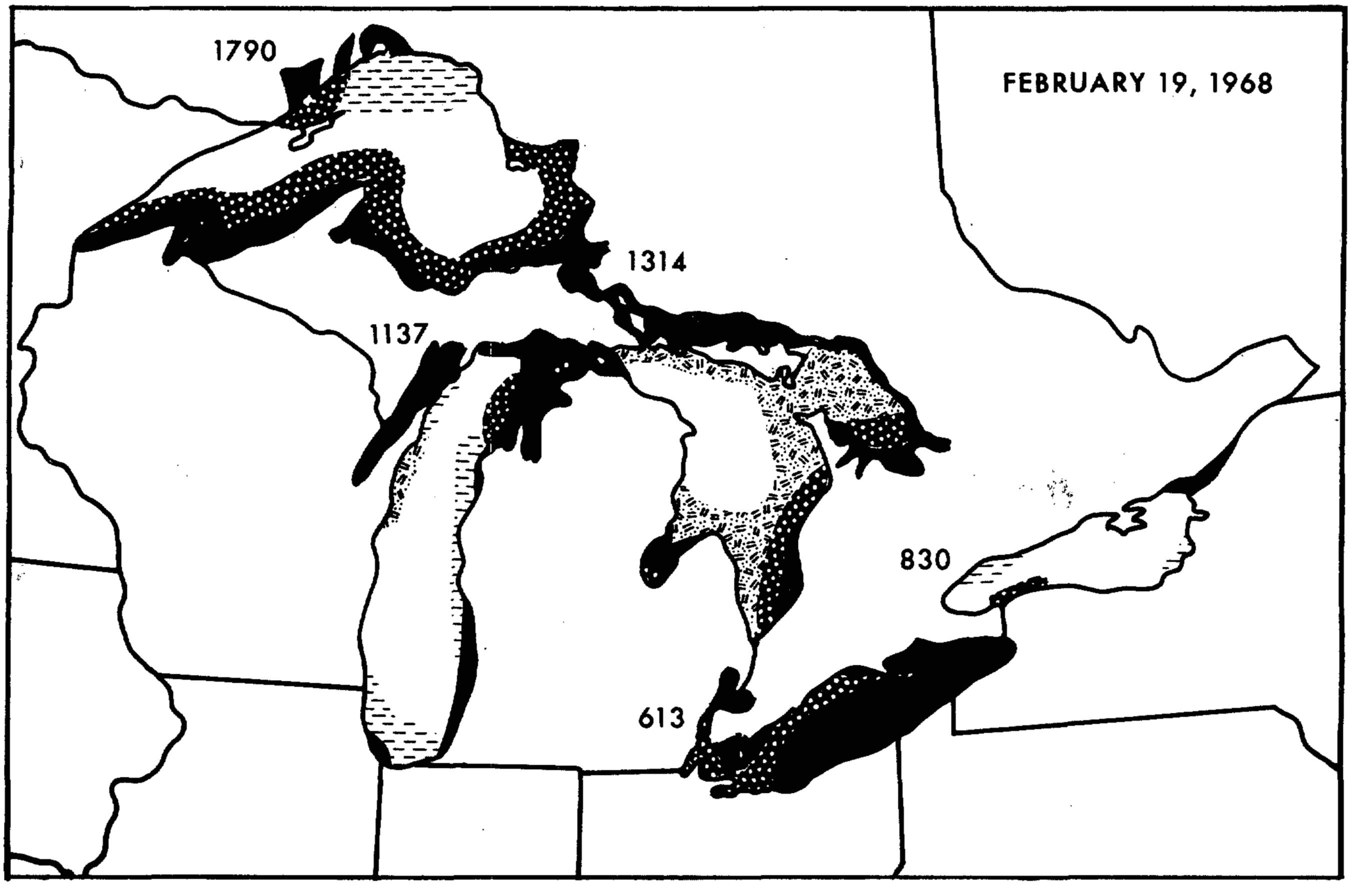

FIGURE 17.—Ice concentration, Feb. 19, 1968 (see fig. 1).

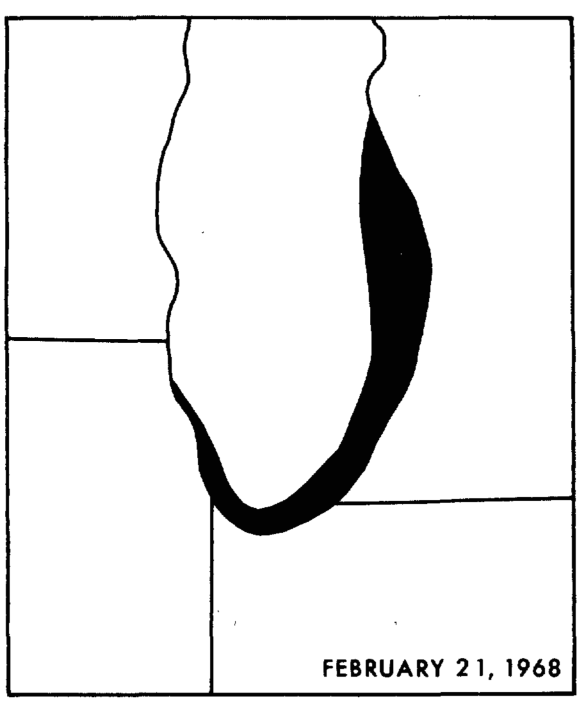

FIGURE 18.—Ice on southern Lake Michigan, Feb. 21, 1968 (see fig. 1).

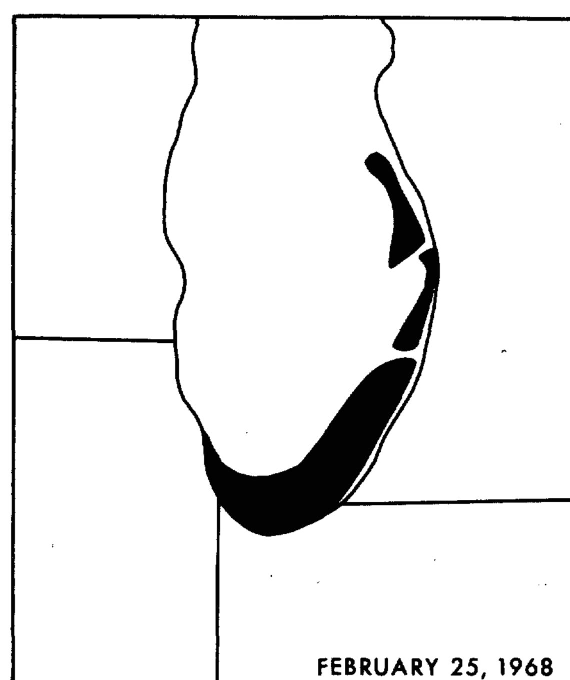

FIGURE 19.—Ice on southern Lake Michigan, Feb. 25, 1968 (see fig. 1).

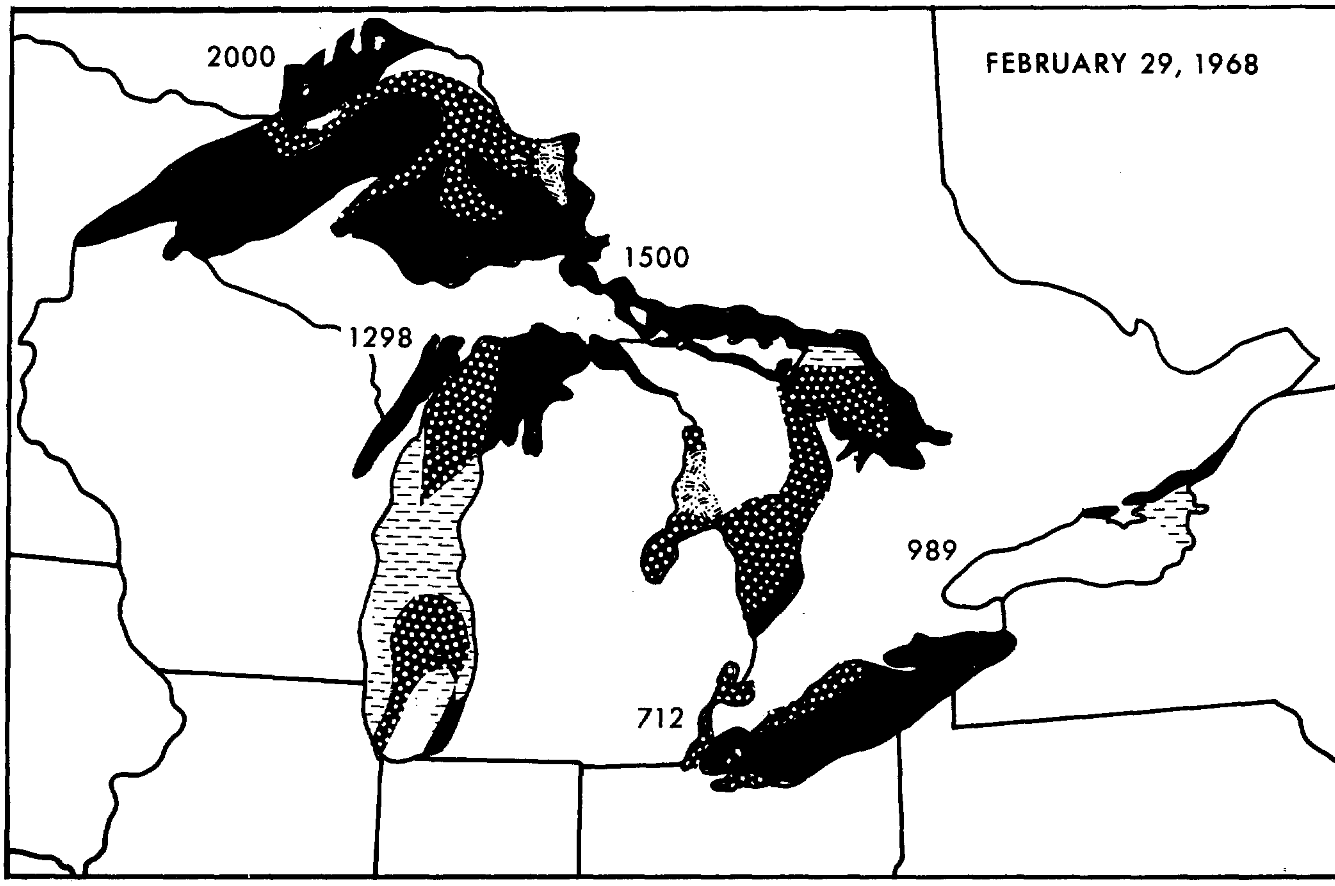

FIGURE 20.—Ice concentration, Feb. 29, 1968 (see fig. 1).

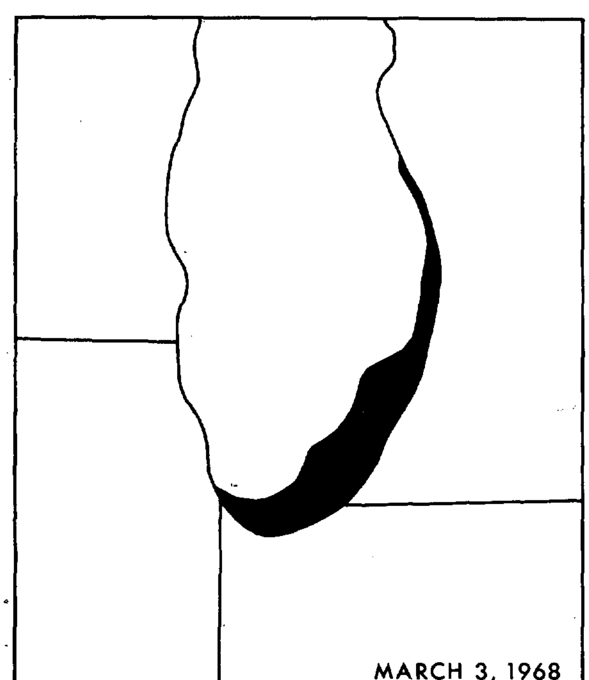

FIGURE 21.—Ice on southern Lake Michigan, Mar. 3, 1968 (see fig. 1).

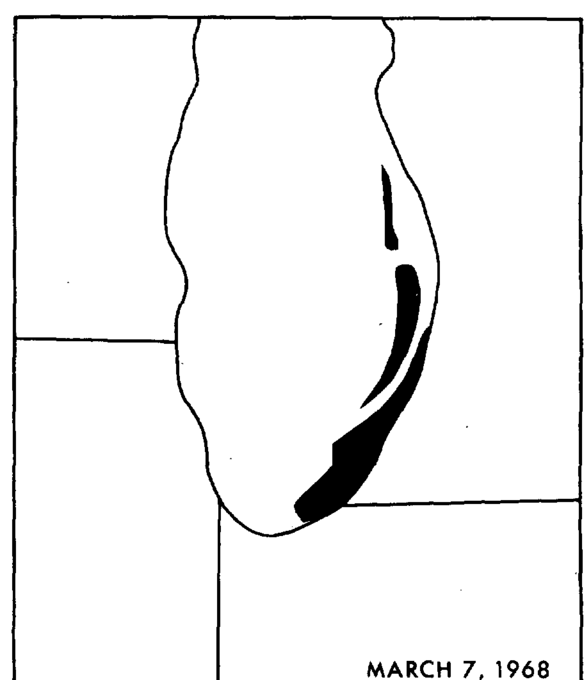

FIGURE 22.—Ice on southern Lake Michigan, Mar. 7, 1968 (see fig. 1).

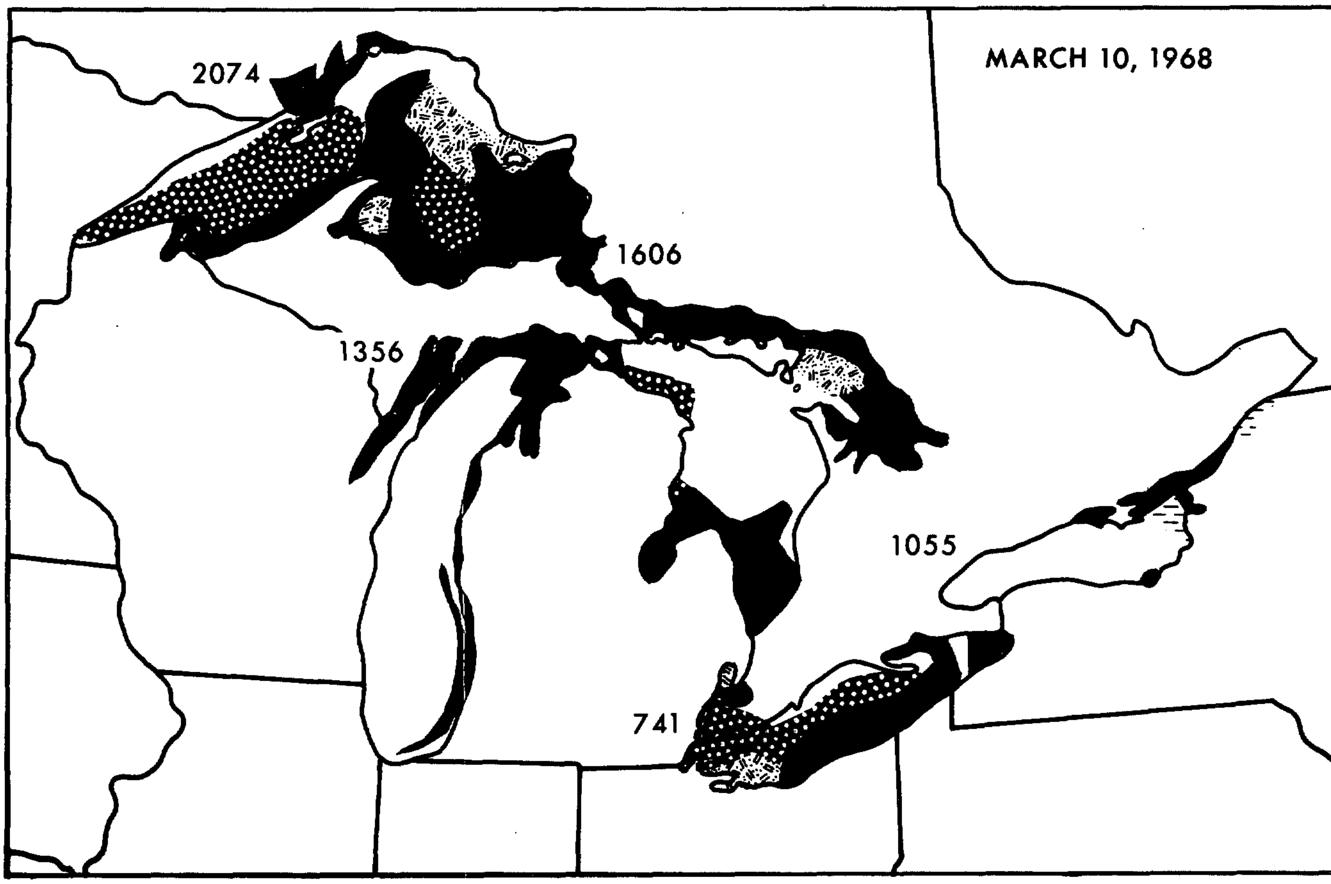

FIGURE 23.—Ice concentration, Mar. 10, 1968 (see fig. 1).

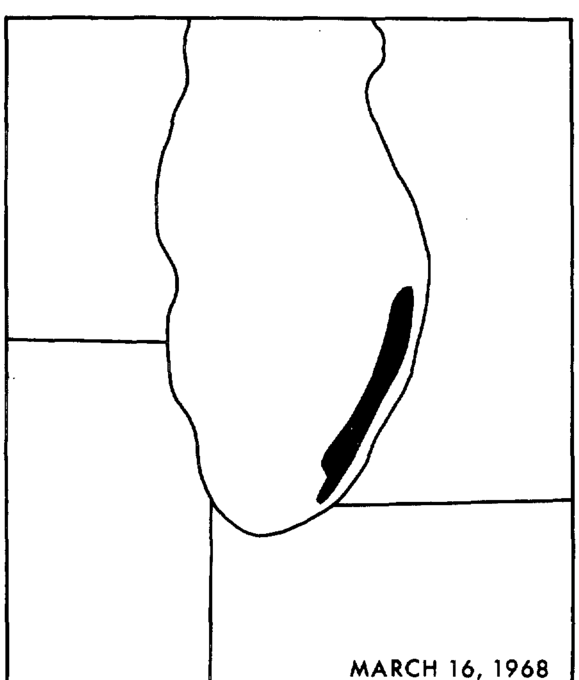

FIGURE 24.—Ice on southern Lake Michigan, Mar. 16, 1968 (see fig. 1).

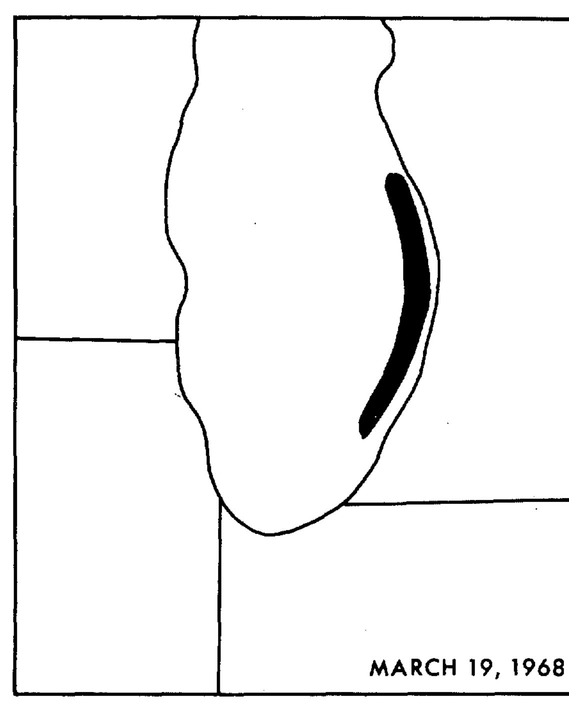

FIGURE 25.—Ice on southern Lake Michigan, Mar. 19, 1968 (see fig. 1).

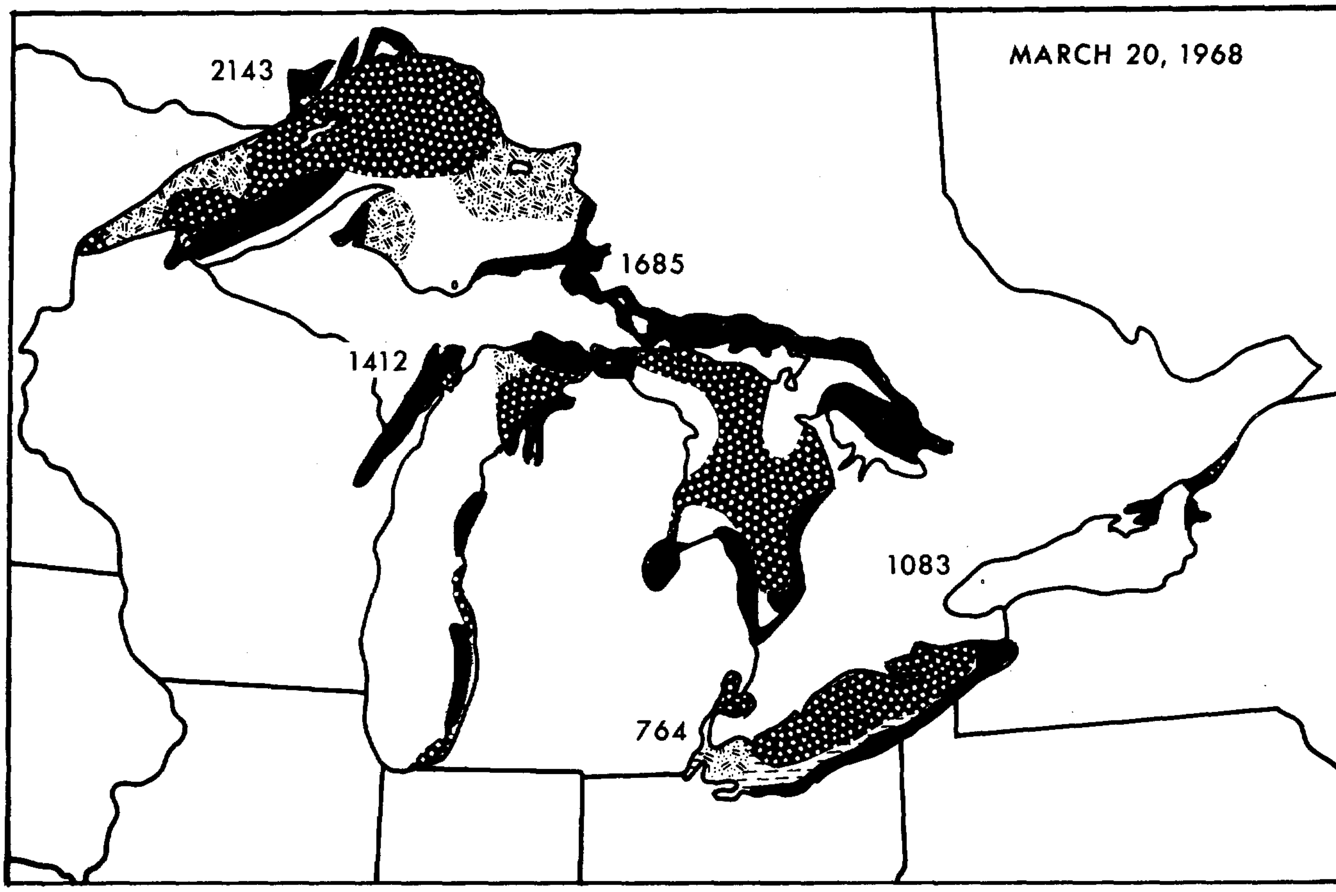

FIGURE 26.—Ice concentration, Mar. 20, 1968 (see fig. 1).

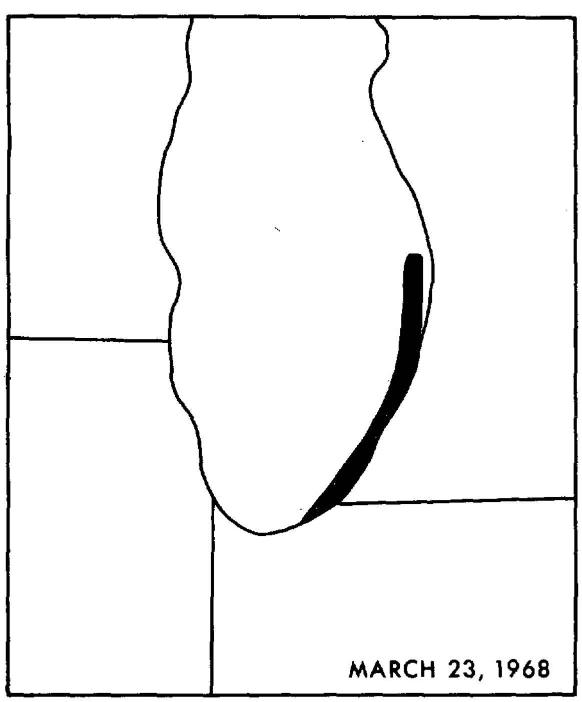

FIGURE 27.—Ice on southern Lake Michigan, Mar. 23, 1968 (see fig. 1).

the entire mass moved 3 to 4 mi offshore (fig. 27). It drifted slowly northward on the 17th, 18th, and 19th (fig. 25) and on the 20th through 22d moved on or near the beach from Muskegon to St. Joseph. The 23d saw it move back south again to lie on shore from Holland to Michigan City (fig. 27). The south half melted or blew into the open lake during the remaining days of March.

The first of April saw a band of jammed pancake ice up to 8 mi wide along the shore from Muskegon to South Haven (fig. 29). This was of great concern to conservation authorities—the Coho salmon-fishing season opened that day. Past experience had shown that sportsmen after this desirable species were prone to take unwise chances with environmental hazards. During April, ice melted slowly from the south (fig. 31). South Haven cleared on the 3d, Holland on the 12th; Muskegon still reported jams up to 24 in. on the 15th. Final melting of the last vestige of this unusual ice feature took place in the last week of April.

7. SUMMARY AND CONCLUSIONS

There is a substantial and increasing demand for more detail and wider coverage in ice forecasts for the Great Lakes. Economic and technological changes have rendered almost meaningless the annual port opening forecasts

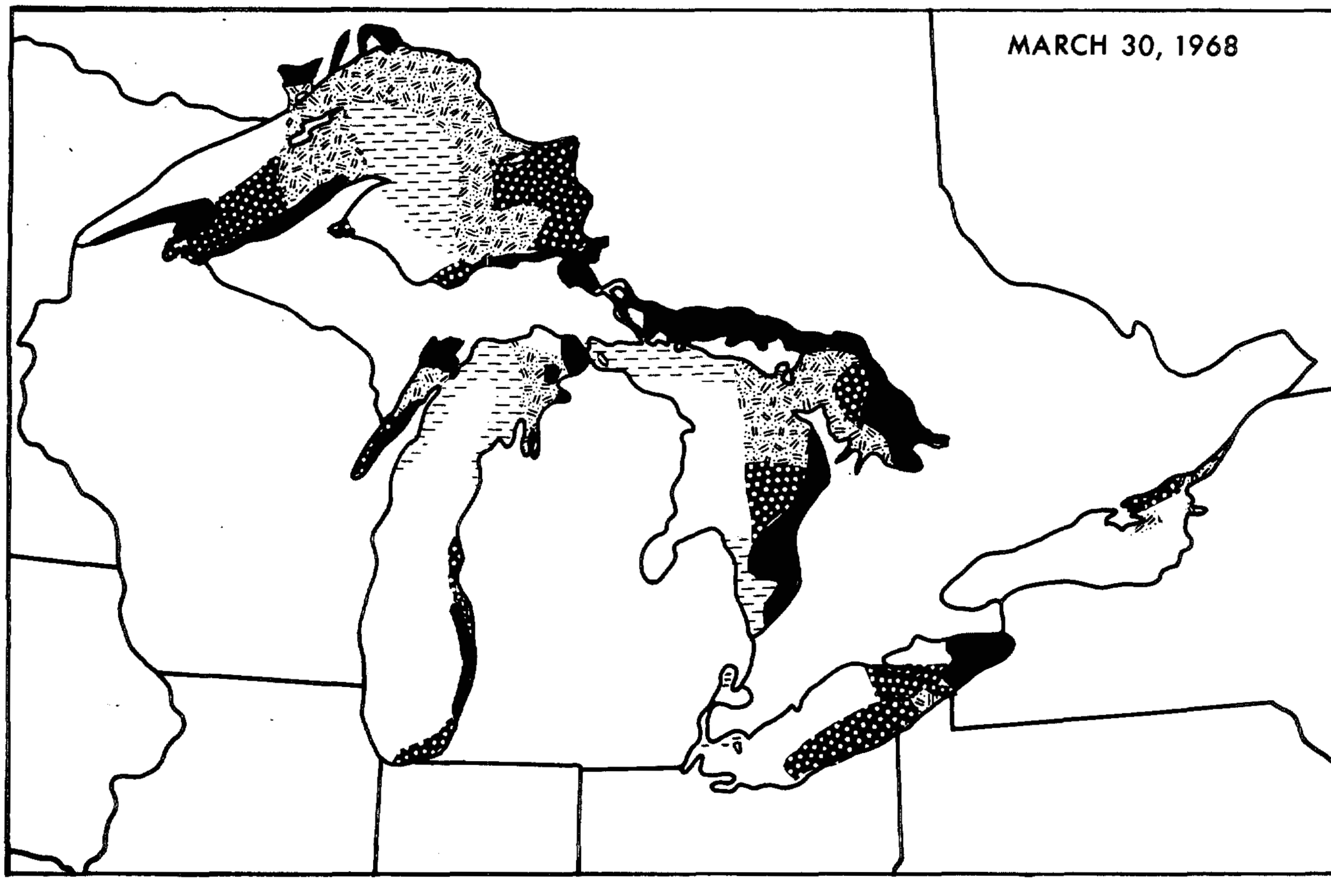

FIGURE 28.—Ice concentration, Mar. 30, 1968 (see fig. 1).

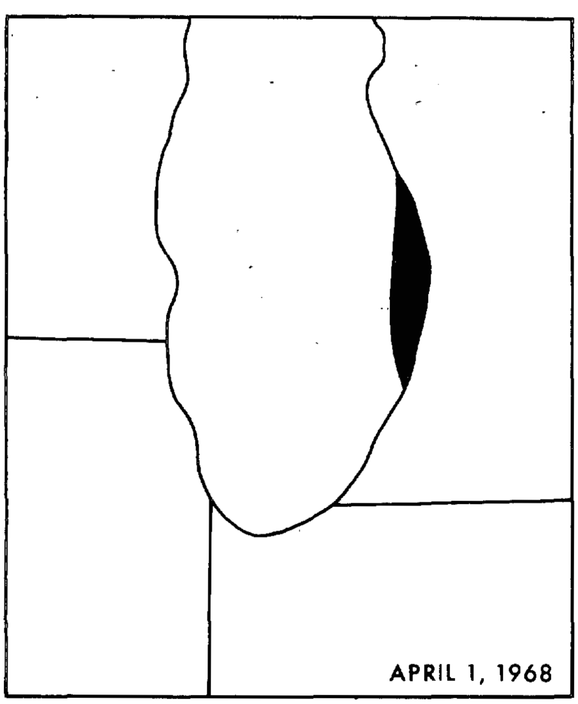

FIGURE 29.—Ice on southern Lake Michigan, Apr. 1, 1968 (see fig. 1).

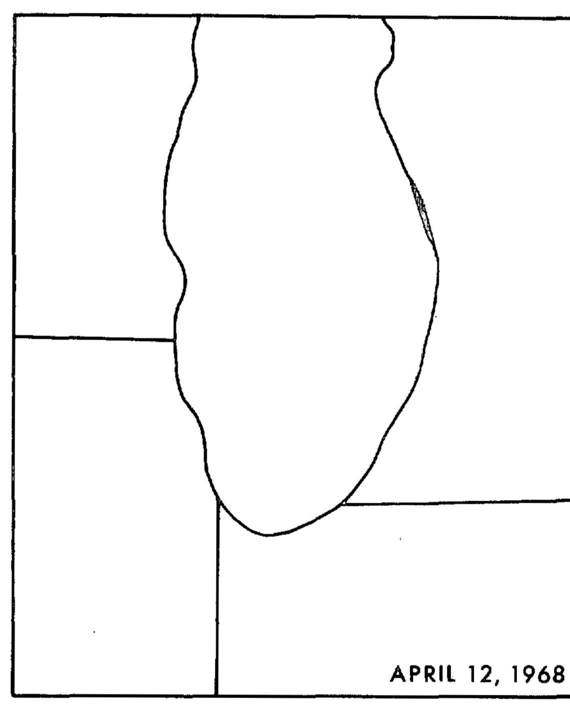

FIGURE 31.—Ice on southern Lake Michigan, Apr. 12, 1968 (see fig. 1).

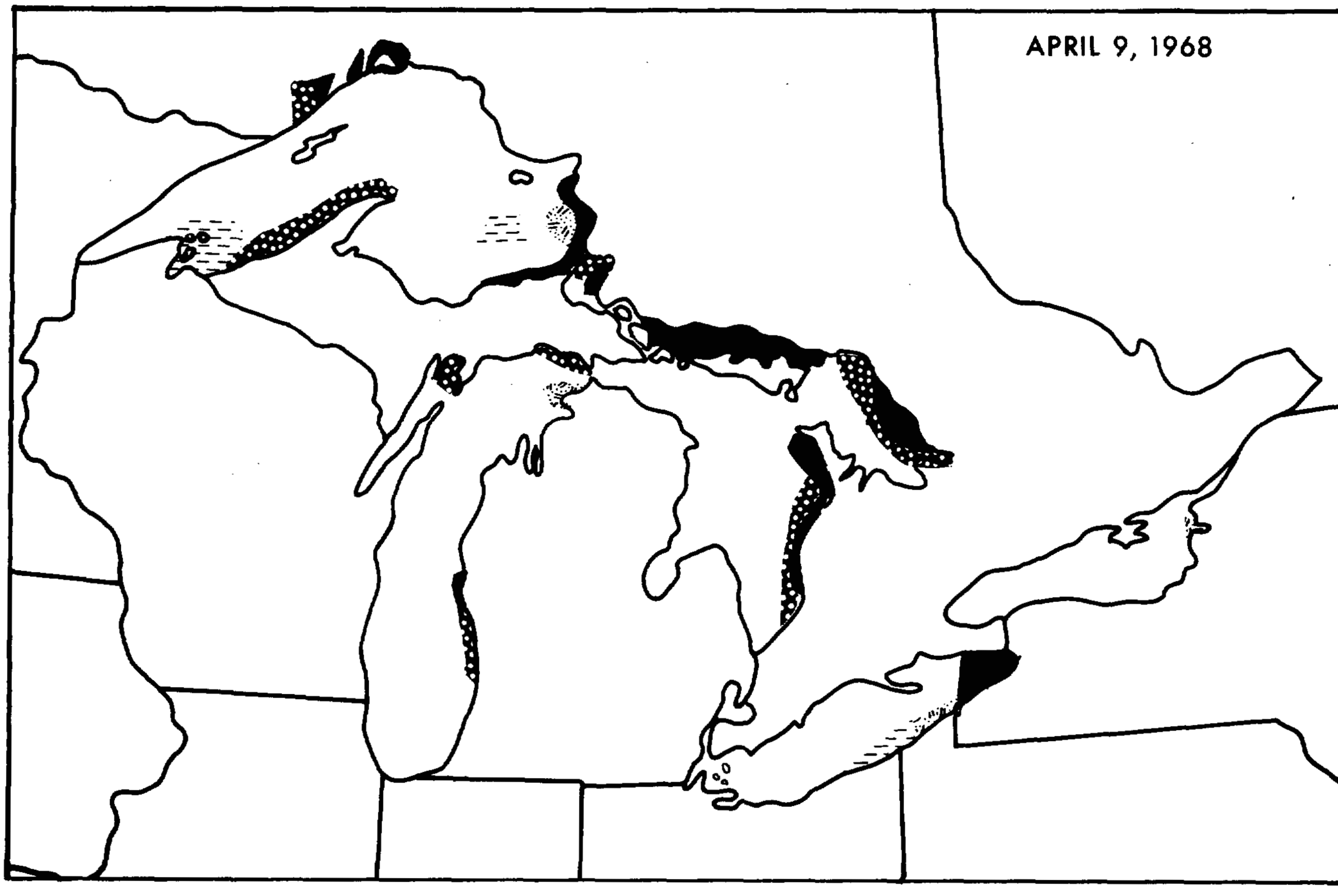

FIGURE 30.—Ice concentration, Apr. 9, 1968 (see fig. 1).

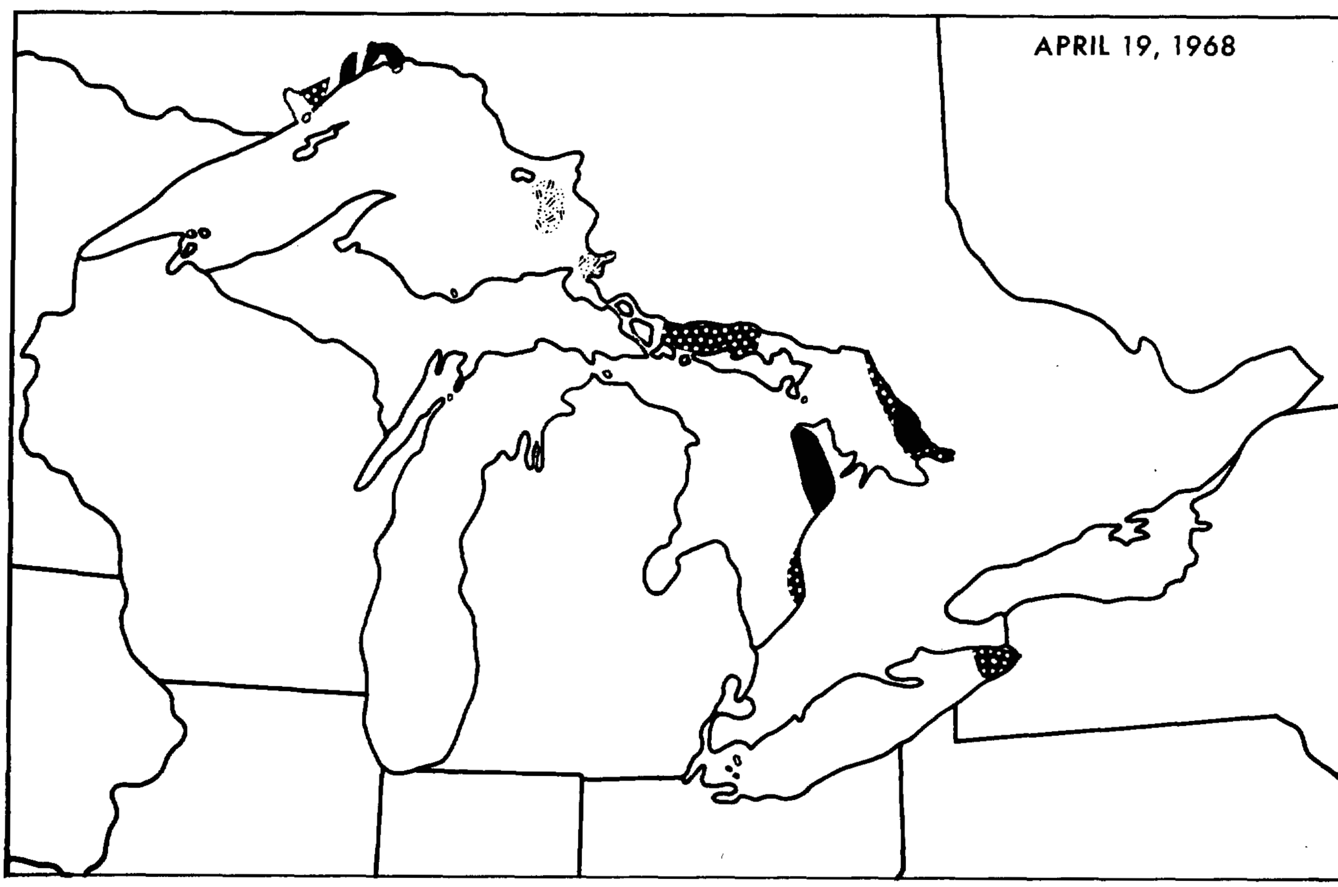

FIGURE 32.—Ice concentration, Apr. 19, 1968 (see fig. 1).

that have been issued in the past. Current forecasts give instead the dates after which icebreaker operations will be profitable and the dates after which they will no longer be required. These forecasts are prepared by a refined and updated version of the February mean temperature relationships that have been used for many years.

An experimental method, based on freezing degree-day and thawing degree-day concepts, is meeting with some success and gives much promise for the future. It incorporates prognostic as well as current meteorological data and predicts freezeup as well as breakup. No such method could have been proposed had not great strides been made in long-range temperature forecasting.

Detailed investigation of special problem areas, such as the Straits of Mackinac and shorelines subjected to heavy windrowing, give valuable insight into the behavior of ice and its interaction with various weather elements.

We have both the observational data and the understanding of physical processes to create a much improved ice forecasting system. Considerable progress has already been made. User requirements for ice information, both current and forecast, are changing and expanding rapidly. Weather forecasting, particularly that involving long-range temperature predictions, must provide important input into any ice forecasting scheme. Conversely, ice information can provide significant feedback into weather forecasting.

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CORRECTION NOTICE

Vol. 97, No. 1, Jan. 1969, p. 84: 4th line after equation (20) should read "initial state, equation (19) is thus . . ."